VOL. 1 No. 1 JANUARY 1936

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

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INTRODUCTION

With the appearance of the first issue of this new periodical, the policy and aims should be outlined which will be pursued in these pages. The Philips Research Laboratories are continually receiving an everincreasing number of enquiries and requests from many quarters for more detailed data and particulars of the extensive range of Philips products, and especially for information as to their specific characteristics and practical applications. A large proportion of these enquiries comes from the engineering world and it is hoped by means of this periodical to establish permanent contact with these circles.

This journal will deal with the following items:

a) Technical descriptions of new Philips products, and reports on investigations relating thereto,

b) Information concerning the applications of these products, and

c) Technical articles of a more general nature on various questions relating to the above, which may be of interest to the reader.

An endeavour will be made to present the subject matter of the articles as simply as possible. Mathematical treatment will be resorted to neither more nor less than is necessary. Facts which can be concisely stated by mathematical formulae will in addition be explained in simple language, which will make it possible for those who do not wish to follow the mathematics to gather the gist of the article from the text alone. Additional clarity will further be strived for by the free use of diagrams and graphs. In this way every unnecessary show of learnedness will be avoided, but on the other hand care will be taken that this simplicity of expression does not lead to superficiality and indefiniteness when dealing with really complicated subjects.

Each contribution to this periodical will be, as far as possible, complete in itself. Owing to the wide range of products manufactured by Philips every article cannot be expected to command the same measure of interest from every reader. Nevertheless, it may be expected that many readers wil find matter of interest also in those contributions which do not concern their own immediate activities.

This periodical therefore will be not merely a journal embracing the activities of the Philips organisation nor a technical journal on popular lines, but a source of information of value and interest to the whole engineering profession. Our hope is that this publication will prove of practical interest and use to many, and in consequence merit a wide circle of readers.

G. HOLST.

COMPARISON BETWEEN DISCHARGE PHENOMENA IN SODIUM AND MERCURY VAPOUR LAMPS

I.

Summary. The visible radiations of sodium and mercury vapour lamps are generated by entirely different processes. Sodium is excited by the impact of electrically accelerated electrons against atoms in the normal state. In high-pressure mercury vapour lamps the radiation is produced by the temperature of the mercury vapour.

Introduction

The technical features of sodium and mercury vapour lamps as regards the state of the metal vapours have developed along very different lines, which in many respects have been tending in opposite directions. Thus it has been found that in general the efficiency of light production in sodium vapour was the higher, the lower the vapour pressure, the current density and the luminous intensity, while that of the mercury vapour lamp in the range investigated increased with these factors. *Table I* brings out the marked difference between these two types of gas-discharge lamps in their present stages of development. This table compares certain essential data of the metal vapours of a commercial sodium lamp with an experimental type of mercury vapour discharge tube of very high efficiency.

Table I. Characteristics of the metal vapour of a sodium tube lamp of 100 watts (Philora type SO 100) and of a super-high-pressure mercury lamp of 1400 watts (experimental type).

	Na	Hg
Pressure in atmos.	10^{-5}	200
Current density in amp/sq.cm.	0.4	280
Cross-section in sq.cm.	1.43	0.0075
Luminous intensity in candles/sq.cm.	10—20	180000
Vapour temperature in deg.C	280	8600
Light output in lumens/watt	68	78

The sodium lamp is surrounded by a double walled vacuum flask which diminishes heat conduction; the mercury vapour discharge, however, is cooled by running water.

The complete divergence in the behaviour of sodium vapour and mercury vapour cannot be readily reconciled with the assumption that the processes responsible for the emission of light from these two classes of lamps are analogous. Closer examination does in fact show that, in spite of a fundamental similarity in the mechanism of the two forms of discharge, there is yet an essential difference between the processes generating the visible radiation. Those prosesses which furnish the useful light in the mercury lamp represent, on the other hand, undesirable losses in the case of the sodium lamp, and vice versa. The explanation of this must be sought in the different structure of the sodium and mercury atoms, and makes it necessary for us to consider the fundamental principles of atomic physics regarding the emission of light from atoms.

Luminous Radiation due to Atomic Processes

In discussing this problem the principles will be followed enunciated in the atomic theory of B o h r. The sodium atom consists of a positively-charged nucleus about which 11 electrons revolve. A measure of the forces linking the electrons to the atom is the energy which must be expended to remove an electron from the rest of the atom. With both the sodium and mercury atoms it has been found much easier to remove the first electron from the atomic system than subsequent electrons, whose separation requires the expenditure of a much larger amount of energy. Ionisation may be produced, for instance, by bombarding the atom with electrons which have been sufficiently accelerated by an electric field that they are able to impart the requisite energy for ionisation to one of the atomic electrons. If an electron with charge e has passed through a voltage drop of V volts and stored the energy:

$$\varepsilon = e V \quad . \quad . \quad . \quad . \quad (1)$$

acquired in this process, it will be termed an electron of V volts.

To be able to ionize sodium an electron must have acquired at least 5.12 volts, while in order to ionize mercury 10.38 volts are required. If electrons with a lower energy collide with the atoms, they will prove too weak to break up the atoms into positive ions and electrons.

The atoms, are, however, able to absorb certain amounts of energy which are smaller than the ionisation energy, but any energy values irrespective of magnitude cannot be absorbed; the energy absorbed must be in specific quanta.

The consequences will be discussed somewhat in detail for sodium atoms bombarded with electrons of steadily increasing velocities. As long as an electron has passed only through a voltage range which is smaller than 2.1 volts, collision is perfectly elastic since the sodium cannot absorb such small energy quanta. But as soon as the electron has passed through a voltage drop of 2.1 volts, it is able to impart the corresponding energy quantum of 2.1 e to the atom. By absorbing this amount of energy ε the atom passes into a socalled excited state, from which it is usually able to return very rapidly to its initial normal state (e.g. after the elapse of about 10^{-8} sec.). During this process it radiates light of a perfectly definite wave-length λ or frequency ν, as expressed by Planck's equation:

$$\varepsilon = h\nu = \frac{hc}{\lambda} \quad . \quad . \quad . \quad (2)$$

where c is the velocity of light and h the constant of Planck ($h = 6.55 \cdot 10^{-27}$ ergsec).

Equation (2) not only applies to the transition from the first excited state to the normal state, but in fact to every transition from one specific energy level to another during which the energy liberated is radiated as light. ε is here the difference in energy between the two states. In the particular case where sodium is excited by electrons of at least 2.1 volts, a yellow light is radiated. Analysing this radiation with the spectroscope, two lines are found, with wave-lengths of 5890 and 5896 Å respectively. These lines correspond to transitions from two states whose energies differ by such a small margin that in practice it is not possible to obtain the lower excited state alone. The wave-lengths agree with equations (2) and (1), from which we obtain the following relationship between the wave-length λ of the luminous radiation in Å and the potential difference passed through:

$$\lambda = \frac{hc}{eV/300}\,10^8 = \frac{6.55 \cdot 10^{-27}\, 3 \cdot 10^{10}}{4.77 \cdot 10^{-10} \cdot V}\, 300 \cdot 10^8$$

$$= \frac{12340}{V}\ \text{Ångström} \quad . \quad . \quad (3)$$

With mercury, electrons of 4.86 volts are similarly found capable of generating the ultra-violet mercury line with a wave-length of 2537 Å.

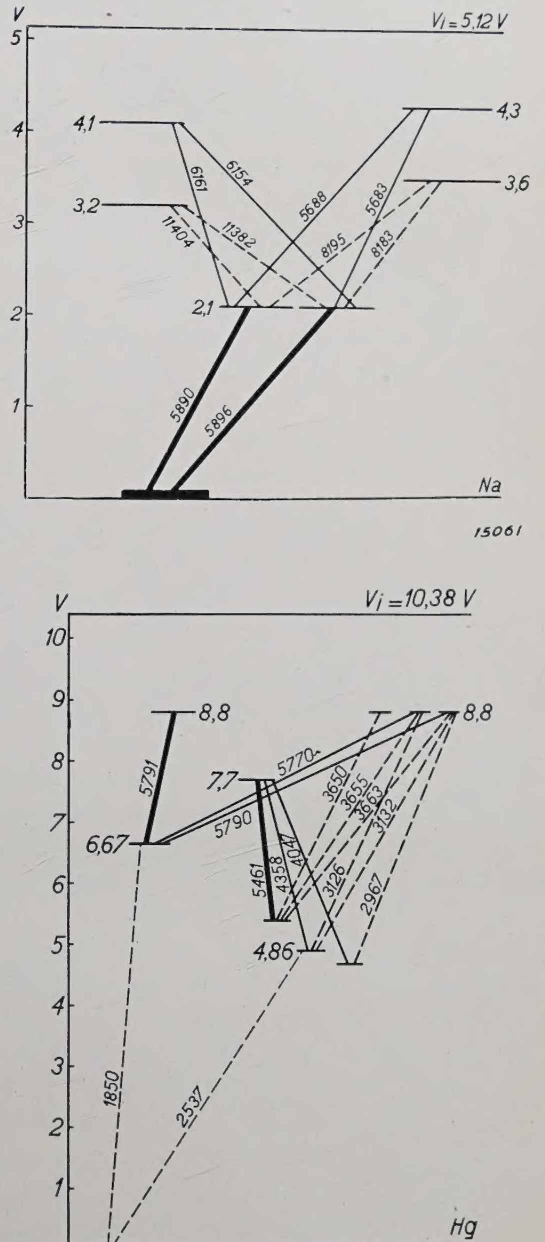


Fig. 1. Energy levels of Sodium and Mercury. The thickness of the lines denotes the visibility of the transition phenomena; invisible (ultraviolet and infrared) transitions are shown as broken lines. V_i is the ionisation voltage. With sodium, visible light is produced mainly by resonance lines (5890 and 5896 Å); higher transitions give infrared radiation. With mercury, visible radiation is produced by higher transitions (mainly 5461 and 5791 Å); the resonance lines (1850 and 2537 Å) are ultraviolet.

If in the case of sodium the velocity of the bombarding electrons is increased, various other lines of the sodium spectrum appear successively. Thus at 3.2 volts two infrared lines in the neighbourhood of 11400 Å are obtained, corresponding to a transition from the 3.2 volt level to the 2.1 volt level, and from 3.5 volts onward there appear the lines 8183 and 8195 Å. In this way the whole of the sodium spectrum is gradually produced, until at 5.12 volts the sodium is ionized. Similarly with mercury, at 6.67 volts there appears in the extreme ultraviolet a line with a wavelength of 1850 Å. From 7.7 volts onwards one gets the wellknown green, blue and violet lines of mercury with wavelengths of 5461, 4358 and 4047 Å, while in the neighbourhood of 9 volts the yellow mercury line 5791 Å appears, as well as a large number of lines which are on the threshold between the visible violet and the ultraviolet.

The energy levels of sodium and mercury may be represented as shown in *fig. 1.* Along the vertical axis the minimum voltage is plotted which the electron must pass through in order to be able to bring the atom into the corresponding state. The individual levels between which a transition accompanied by radiation may occur are joined by lines, whose thickness corresponds roughly to the intensity of the visible light obtained. These diagrams clearly show that not all possible transitions are obtained with noticeable intensity, thus e.g. there are no combinations between the energy levels in one and the same column. In fact, whether reciprocal combinations are possible or not with the emission of radiation has determined this distribution of the different energy levels over a number of columns. This question cannot be discussed in detail within the scope of this article.

The diagram shows that the common yellow sodium lines which make up the larger part of the visible light emitted by sodium lamps are radiated on the transition of the sodium atom from the lowest excited state to its normal state. The analogous process with mercury gives an invisible ultraviolet line and must therefore be regarded as undesirable. On the other hand, the visible mercury lines in the green and yellow are due to transitions between higher levels, which in the case of sodium mostly produce infrared lines. To this is due the fundamental difference in the behaviour of the sodium and mercury vapour lamps.

Energy can be imparted to an atom not merely by bombarding it with high-speed electrons, but also by causing the atom to absorb radiation or raising the gas to a high temperature. In these processes also it is found that the atom can absorb energy only in definite quanta. If the temperature is not too high, practically all the atoms are in the normal state and they then absorb only such light quanta, as are radiated on return to the normal state. The smallest light quantum which can be absorbed is that corresponding to a transition from the normal state to the nearest excited state; A spectral line radiated on return to the normal state is termed a resonance line.

The resonance lines play an important part, as they are strongly absorbed by the gas itself. If the pressure of the metal vapour is not extremely small, the intensity of the resonance radiation is considerably weakened by self-absorption. Self-absorption is not intrinsically a loss in luminosity, as the absorbed energy is usually emitted again in the form of a light quantum of the same wave length. But it may happen that an atom before radiating the absorbed light quantum is excited to a higher degree by collision with an electron (cumulative excitation) or transfers its energy to an electron and thus returns to the normal state without emitting radiation (collision of the second kind).

It is obvious that the weakening of the resonance radiation in gaseous discharges is determined not only by the intensity of self-absorption, but also by the relative occurrence of the secondary processes referred to. Self-absorption increases with the pressure, while the secondary processes increase with the current density.

Conclusions bearing on the Design of Sodium and Mercury Vapour Lamps

The above considerations show that to obtain a high output of visible radiation from sodium vapour and mercury vapour lamps entirely different methods must be adopted. To obtain a high yield of light rays with sodium, it is essential for the resonance radiation to predominate and transitions between higher energy levels to be suppressed as far as possible. On the other hand in the mercury vapour lamp the discharge must be such that the maximum radiation is obtained by transitions between high energy levels.

As already indicated in the previous section, resonance lines are easily and considerably weakened by self-absorption. This weakening is undesired in the sodium lamp, but highly desirable in the case of the mercury lamps. As this weakening due to self-absorption increases with the gas pressure and the current density, it appears that

to obtain the best results, sodium lamps should have a low vapour pressure and be run on a low current density, and mercury lamps have a very high vapour pressure as well as a very high current density.

How far the adoption of these principles would result in an increase in the light output of sodium and mercury lamps will be discussed in a later paper. Certain results will, however, be briefly referred to here owing to their general interest, although they do not completely bear out the considerations above. It has been found that in the sodium lamp radiation is produced as a result of excitation by electronic collision. On the other hand, when passing a discharge through mercury vapour at a high pressure, the conditions of excitation and ionization are determined by the temperature of the vapour, in other words the vapour atoms behave as if they were contained in a closed vessel at a constant temperature. In spite of the input of energy by the current and the output of energy by radiation, a thermal equilibrium is roughly established. This is due to the fact that owing to the high concentration of the mercury atoms the energy stored in the gaseous column as heat is much greater than the energy input and output during a specific time interval sufficient for thermal equilibrium to be established.

In the case of sodium, nearly the whole of the energy of the electrons is converted to resonance radiation, when the current density is extremely low and the vapour pressure has a suitable value. In practice this limiting case is not approached, because inter alia part of the energy must be converted to heat in order to maintain the walls at such a temperature that the vapour pressure of sodium has a satisfactory value. The energy lost by thermal radiation increases with the area of the radiating surface. Therefore a specific luminous flux should not be radiated through an excessive area. The luminous density and hence also the current density must therefore not be too low.

The spectral distribution of energy in the radiation of high pressure mercury vapour presents a very complex problem. With rising vapour pressure, the relative concentration of mercury molecules Hg_2 also increases. These molecules give a spectrum, composed of wide bands instead of sharply defined lines. As a result the line spectrum will gradually become covered by a continuous background, the transition becoming the more marked as the vapour pressure rises. *Fig. 2* shows the spectra obtained with a super-high-pressure mercury vapour lamp at different vapour pressures.

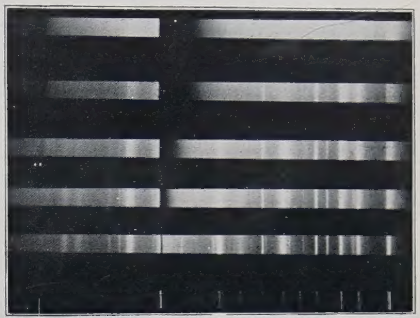


Fig. 2. Spectrum of a mercury vapour discharge, cooled with a stream of water, at different vapour pressures P. With rising vapour pressure, the spectrum lines will progressively be covered by emission and absorption bands. (Internal diameter of tube 2 mm, current intensity approx. 1,3 A).

The most striking difference in these spectra is the steady intensification of the continuous background beginning at the resonance line 2537 Å and spreading mainly in the direction of the longer wavelengths. With the increase in vapour pressure an absorption band progressively covers a greater part of the spectrum owing to self-absorption of the resonance radiation. The appearence of the bands may be regarded as the first stage of the transition of radiation into a state of thermal equilibrium, where the spectral distribution of intensity is no longer determined by the characteristics of the individual atoms but merely by Planck's law of black body radiation. Since a black body at the temperature of the radiating zone in the discharge emits comparatively more red radiation and less ultraviolet radiation than a mercury vapour lamp, it may be concluded already from thermodynamical considerations that with rising vapour pressure the center of gravity of the intensity distribution becomes shifted towards longer wavelengths. This effect is indeed clearly brought out in fig. 2. The wide absorption bands produced by a broadening of the resonance lines weaken the ultraviolet radiation of the mercury vapour to a degree which increases with the rise in vapour pressure, while the continuous background which increases in intensity with the pressure stretches far into the red and infrared region of the spectrum.

Compiled by G. HELLER.

A MODERN HIGH-VOLTAGE EQUIPMENT

Summary. The equipment described furnishes peak voltages up to 1000 kV, and a D.C. voltage of 700 kV, a current of 4 milliamps being derived. Compactness and simplicity of control are its features. The installation is composed of two symmetrical units. One unit comprises four stages, each consisting of a condenser and valve; each structural element is subject to a quarter only of the total voltage. Owing to their special design, the valves are able to cope with a 200 kV backfiring voltage. The oxide cathodes are heated by means of a high-frequency generator.

Introduction

The problem of generating D.C. voltages up to several hundreds of kilovolts has been stimulated in a high degree by the development of atomic physics, which has acquired considerable proportions during the last few years. For experiments on the disintegration of atoms a very large number of high-voltage equipments complying more or less with the special requirements have been designed and constructed. But most of these equipments take up a great deal of room and demand much of the experimenter's attention, which, therefore, has to be necessarily divided between the actual experiments in hand and the apparatus supplying the requisite high voltage. An installation which, while not relieving the experimenter from every such duty, yet does simplify supervision to a marked degree, has been developed in the X-ray laboratory of the Philips Works [1]). This equipment, which supplies a direct current of 4 mA at 700 kV and peak voltages up to 1000 kV, takes up very little space and is remarkable for the simplicity of its construction and operation.

The theoretical lay-out of this installation is based upon a circuit, first described by Greinacher. Cockcroft (Cambridge), and Bouwers (Eindhoven), working independently almost simultaneously thought of applying this principle for generating very high voltages.

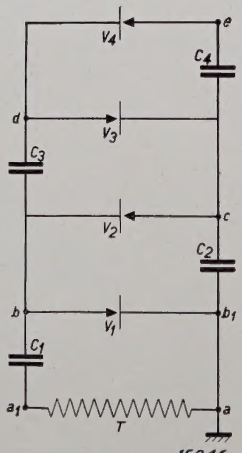


Fig. 1. Principle of the Greinacher circuit. If transformer T supplies an A.C. voltage of amplitude E, point c is at a constant voltage 2 E and point e at a constant voltage 4 E with respect to earth. The circuit can be expanded as required.

Principle of circuit

The fundamental diagram is shown in *fig. 1.* The secondary winding T of a high-tension transformer furnishes an A.C. voltage of amplitude E. Point a is earthed and is thus always at zero potential. (This fact is not essential, but it is stated to facilitate a clear understanding of the circuit). Point a_1 has a voltage with respect to earth, which is represented by the voltage-time sine curve a_1 in *fig. 2.* How will the voltage at point b vary with time?

Fig. 2. Voltage-time curves for various points of the circuit in fig. 1. Across each valve the voltage fluctuates between zero and 2 E; for adjacent valves the phase-displacement is half a cycle.

In the absence of valve V_1, the upper plate of condenser C_1 would alternately assume a positive and negative charge, whose maximum value would

[1]) A short description of the equipment — which has since been much improved — has been published by A. Bouwers ("Modern X-ray Development", British Journal of Radiology 7, 21, 1934).

correspond to the peak value E of the transformer (it amounts to E times the capacity of C_1). As, however, valve V_1 permits the current to flow in circuit $a\ a_1\ b\ b_1\ a$ in one direction only (viz. to the left) [2]), the positive charge once accumulated on the upper condenser plate will be maintained, as the deficiency of electrons cannot be made up via V_1. Condenser C_1 is thus charged to the peak voltage E, and the potential at b consequently remains $+$ E in excess of that at a_1 (or —E, if the valve is reversed). The potential at b which with respect to earth is identical to the voltage across valve V_1 can obviously be represented by curve b: it oscillates between zero and 2E.

The same reasoning may be followed for ascertaining the fluctuation of the potential at point c of the adjacent circuit. The voltage across valve V_1 which oscillates between zero and 2E, here performs the function of the A.C. voltage supplied by the transformer; owing to the action of valve V_2, condenser C_2 is charged to the highest voltage occurring at V_1, viz. 2E. Point c, therefore, has a constant potential 2E with respect to b_1 (= earth) (cf. line c, fig. 2).

Between points c and b, i.e. across valve V_2, a voltage occurs which can readily be found as the difference of the potentials at these points, that is, the difference between the ordinates of curves c and b (cf. the shaded area V_2.) It is seen that the valve-voltage V_2 oscillates between zero and 2E (which was also the case with valve V_1), this voltage being displaced by half a cycle with respect to that of V_1. Starting with V_2 and proceeding by the same method, it is similarly found that at point d the voltage fluctuates between 2E and 4E; and also, that point e acquires a constant voltage 4E (cf. curves d and c in fig. 2).

If, for instance, the original A.C. voltage E is 100 kV, a D.C. voltage 4E = 400 kV is obtained at c; by means of a second unit devised on the same lines but having valves operating in the opposite direction, a voltage of —400 kV can be obtained. Between the terminals of the two systems a total voltage 8E = 800 kV will therefore obtain. From fig. 2 it will be evident that in the unit described, voltages still higher than 4E occur: between points e and a_1, the voltage fluctuates between 3E and 5E. By earthing point a_1 instead of a, a peak voltage as high as 5E per unit may be obtained, so that two units in combination are able to supply a peak voltage of 10E.

[2]) In the symbol for the valves used in fig. 1, the arrow denotes the cathode; the arrow consequently indicates the direction of the flow of electrons.

The main advantage of this circuit is that all condensers and valves are subjected to a fraction of the voltage only (viz. 2E, and even E only in C_1). This has enabled the dimensions of all components to be kept within reasonable limits. Moreover, each unit is composed of identical stages, so that still higher voltages can be attained by increasing the number of stages per unit.

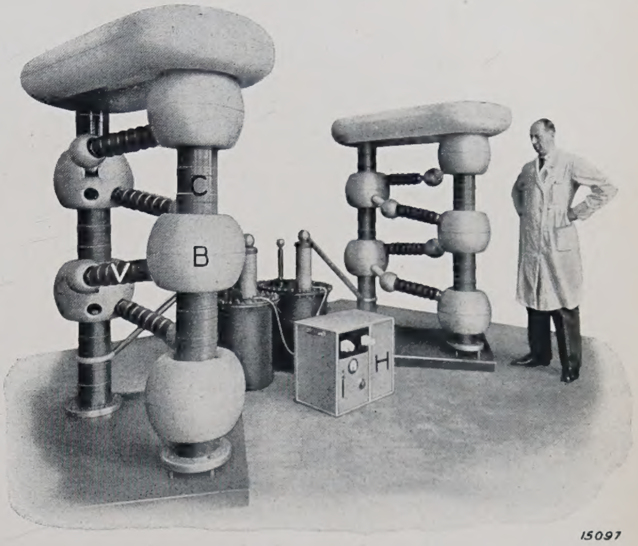


Fig. 3. Complete equipment consisting of two units. The metal globes B enclose the connecting points to eliminate corona phenomena. Between the globes the condensers C which form the vertical structural elements are visible; the valves V are fitted in the sloping interconnections. The transformer is at the rear, the transmitter H for high-frequency heating is in the front.

Description of equipment

Fig. 3 shows a photograph of the complete equipment, comprising two units of four stages each. At both sides of each unit the condensers C(paper condensers of about 0.01 μF) can be seen mounted vertically; the valves V are contained in the sloping connecting members. The connecting points b, c, d and e are surrounded by globe-shaped metal shields B to decrease corona phenomena. Theoretically, a maximum D.C. voltage of 800 kV is obtained between the terminals if the amplitude of the transformer voltage amounts to E = 100 kV. (When the system is loaded this voltage will be somewhat lower because the condensers cannot maintain their peak voltages. Also, a ripple amounting to a small percentage will occur in that case). By a slight modification of the circuit, it is possible, as already mentioned, to obtain a voltage fluctuating between 600 and 1000 kV.

It has already been pointed out that this type of installation is not by any means bulky, the

equipment shown in fig. 3 occupying a floor area of only 1.5×3 m and being only 2 m high. It can, therefore, be accommodated in a comparatively small room.

The valves

Among the various components constituting the equipment, the valves designed by M u l d e r [3]) (Eindhoven) call for special mention. They contain mercury vapour at saturation pressure (approximately $2 \cdot 10^{-3}$ mm at 15° C) and are provided

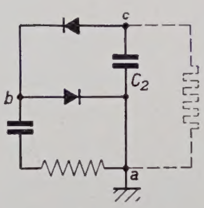


Fig. 4A. Two-stage unit. Starting at instant t_0 a current is taken from *c*.

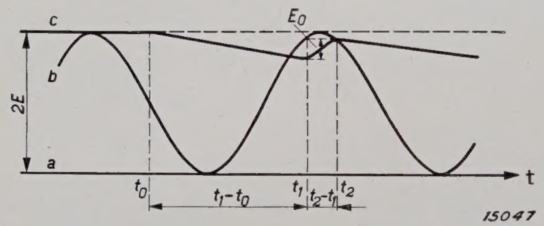


Fig. 4B. The variation of potential at points *b* and *c* is similar to that in fig. 2, but the potential of *c* slowly decreases from the instant t_0. At t_1, the potential difference across the valves (between points *b* and *c*) attains the value of the ignition voltage E_0; ignition is effected, the potential at *c* increases up to t_2. During the short interval t_2—t_1 the whole charge of condenser C_2 lost during the long interval t_1—t_0 has to be made up. The charging current must therefore assume high momentary values during this short interval.

with oxide cathodes. It is true that, compared with high-vacuum valves, gasfilled tubes have the disadvantage of a high ignition voltage (about 7 kV). Moreover, their operation sets a limit to the ambient temperature, such that in view of the mercury-pressure required, the permissible temperature range is restricted to between about 15° and 40° C. On the other hand, they offer the advantage of a very low voltage drop (50 volts); their main feature, however, is that they enable oxide cathodes to be used which require very little heating and thus facilitate the application of "high-frequency heating", described below (the power required for heating tungsten cathodes is about ten times greater).

[3]) cf. J. G. W. M u l d e r, Dissertation, Delft 1934.

Notwithstanding the fact that the high-tension equipment has to supply a current of a few milliamps only, the cathodes must be designed for an emission current of about 100 milliamps, for the instantaneous values of the charging currents in the valves are many times greater than the current to be ultimately supplied. This point will be considered in some detail, as it is of paramount importance to the efficient functioning of the installation.

When the equipment has to supply current, the functioning of the installation is explained on the same lines as outlined above, except that the potentials of the condensers are somewhat reduced as a discharge occurs. The state of affairs is shown in *fig. 4B*, for an installation of only two stages, up to *c* (*fig. 4A*), and assuming that at a certain instant t_0 the current is drawn from point *c*. The potential at *c*, which was initially 2E, now slowly drops as condenser C_2 is discharged. At a certain instant the potential at *b*, which, as previously stated, fluctuates between zero and 2E, will be in excess of the decreased potential at *c*; when the excess voltage reaches the value E_0 of the ignition voltage — at the instant t_1 — the valve is started up and the condenser C_2 becomes recharged. The potential at *b*, however, remains only a short time at the peak around 2E; it decreases again, whilst the potential at *c* increases. Shortly after, at the instant t_2, the potential difference at the valve becomes zero and the charging current is interrupted. From this point, the cycle is repeated. In order to prevent the condenser voltage from decreasing regularly at intervals, it is necessary to restore to the condenser in the short period t_2—t_1 that charge which has been lost during the long period t_1—t_0 by the discharge current. As the charge is represented by the integral of the current over the time, it is clear that owing to the short duration of the charging current its magnitude must be correspondingly greater; it should exceed the discharge current by the ratio between the time intervals t_1—t_0 and t_2—t_1 [4]).

The oscillogram of the current of condenser C_2, shown in *fig. 5*, clearly shows how the condenser is discharged with a small current and how the charge is restored in a few peaks.

Moreover, the importance of using valves with a l o w ignition voltage will now be evident. If the

[4]) If the potential at *c* is decreasing more quickly, point t_1 is shifted to the left and the ratio of the time intervals becomes more favourable, but the potential "ripple" at *c* is then very large.

ignition voltage is high, it may happen that, at the first "crossing" of the potential at *b* and *c* (point t_1 in fig. 4B), no ignition of the valve at all takes place, so that the condenser is still further discharged, until recharging occurs at the next "crossing", or even later! In this case the time interval for restoring the charge has become still more unfavourable.

Fig. 5. Oscillogram of current in condenser C_2 (of fig. 4A), showing the small discharge current (below the zero-line) and the peaks of the charging current (above the zero-line, about 10 times as large).

The valves used are provided with oxide cathodes consuming about 8 watts, which is ample for obtaining the necessary emission current.

As the cathode is at a potential of several 100 kV, the heating power supply presents a problem in itself. Cockcroft made use of small storage batteries, which were placed directly on the condensers. This seems to be a simple solution, but the regular charging and supervision of the batteries necessary are serious drawbacks and prove very inconvenient. In the case of the equipment described here, the cathodes have for some time been heated by small generators, a method also employed by Cockcroft. The generators were mounted on the condensers and were driven in pairs by a motor on the floor through a common insulating pertinax shaft. This solution is fairly satisfactory, but has the drawback that operation is not noiseless.

The high-frequency heating

The heating problem was later solved in a more elegant way by the application of high-frequency heating, a method suggested by Kuntke (Eindhoven). The circuit at present used is shown diagrammatically in *fig. 6* (only one of the two units is shown).

The condensers C_1-C_4 act as insulators for the D.C. voltage produced, but allow a high-frequency alternating current to pass freely. Between the points *a* and b_1 (*a* is at zero potential) an alternating voltage is applied with a frequency of $7.5 \cdot 10^5$ c/s (corresponding to a wavelength of 400 metres) and derived from a small 150-watt transmitter H. This A.C. voltage now delivers current to the high-tension circuit without affecting the high tension and without being affected thereby. This implies, however, that the circuit must be suitably dimensioned to carry both kinds of

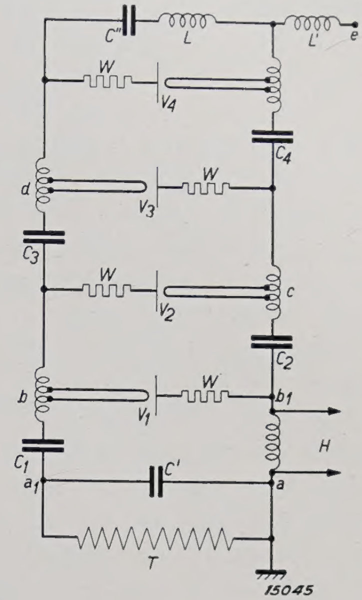


Fig. 6. Circuit diagram of a single unit, with supplementary high-frequency heating. Through the high-tension circuit there also flows a 750 kc current of 0.7 amp; by means of specially-designed air-core transformers (at *b*, *c*, *d* and above C_1), the requisite value of 3.5 amp for heating the cathodes is obtained. The functions of the supplementary components (capacities, inductances and resistances) are explained in the text.

current; the condensers for instance must be designed in such a way that, apart from the required capacity and disruptive strength, they involve only small high-frequency losses. Notwithstanding the special design, the high-frequency losses in the condensers are still comparatively high. Therefore it was desirable to restrict the high-frequency current intensity to 0.7 amp. To obtain the 3.5 amp current required for heating the cathodes, small air-core trnasformers of a 5 : 1 ratio have therefore to be included in the circuit (cf. fig. 6). The necessary power of 8 watts is arrived at by constructing the air-core transformers with a tight coupling and low leakage; the secondary voltage is derived from taps on the coil, as in an auto-transformer. All cathodes are thus heated in a series circuit.

Some details of the diagram shown in fig. 6 may be referred to. The resistances W of 20000 ohms, connected in series with the valves, were originally designed to limit the initial current at the moment of ignition; now they also serve to prevent the valves from providing a shunt for the high-frequency current. For the high-frequency current the capacity C′ shorts the transformer,

while capacity C″ bridges the last valve. The self-inductance L is used to tune the circuit to resonance and, therefore, to reduce the impedance of the high-frequency circuit to the minimum possible. The choke coil L′ prevents the high-frequency circuit from passing over to the loading circuit.

The design of the valves is such that the discharge path between cathode and anode is sub-divided by a number of short metal tubes. The valves are glass tubes about 50 cm long and 3 cm in diameter; the cathode-anode distance d is about 30 cm and is sub-divided by means of 60 tubes in such a way that the distance c between the small tubes amounts to about 0.5 cm (cf. *fig. 7*).

The function of the tubes, which may be regarded as intermediate electrodes, is to increase the back-firing voltage; this is briefly explained as follows: The break-down voltage depends on the vapour pressure and the distance between the electrodes. When the distance between the electrodes is decreased, with a fixed vapour pressure, a region is ultimately reached in which the break-down voltage i n c r e a s e s with d e c r e a s i n g electrode-distance [5]). Roughly speaking, this condition prevails when the mean free path of the electrons in the vapour is of the same order of magnitude as the distance between the electrodes. Then, owing to the deficiency of the number of collisions, the electrons do not produce a sufficient quantity of ions to cause a discharge. Now the mean free path of the electrons in mercury vapour at a pressure of about $2 \cdot 10^{-3}$ mm is of the order of a few centimetres and is therefore comparable to the distance between the small tubes. The latter are interconnected by condensers; this affords a linear potential distribution along the discharge-path, which is necessary during the period during which the tube has to stand the full voltage (2E). The dielectrics of these condensers are constructed as rings of high-tension Philite and fitted round the valve-tube, and thus give the valves the striking appearance shown in fig. 3.

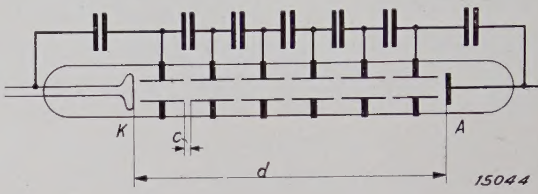


Fig. 7. Construction of valve: the distance d = 30 cm between cathode K and anode A is subdivided by 6 tubes each separated by a distance c = 0.5 cm to increase the backfiring voltage. The bridging condensers produce uniform distribution of the total voltage along the tube.

Compiled by S. GRADSTEIN.

5) Cf. e.g. J. J. Thomson and G. P. Thomson, Conduction of electricity through gases, Cambridge 1933, Vol. 2, p. 475 ff.

RELAY VALVES AS TIMING DEVICES IN SEAM-WELDING PRACTICE

By D. M. DUINKER.

Summary. The usual method of bonding two pieces of metal by spot-welding is to pass a very high-ampere alternating current through them. Practical experience in recent years has shown that to obtain a reliable bond it is essential to limit the time the current is passing to a few hundredths of a second, i.e. to a small number of periods at a 50-cycle frequency. In welding long seams the parts to be bonded are passed between roller-type electrodes at a constant speed, a series of welding-spots being produced by passing a current impuls of the above mentioned duration through the electrodes at uniform intervals. A timing device designed for this purpose must therefore allow the current to pass for a certain number of cycles x, then arrest the current for a further number of cycles y and repeat this sequence (x+y) continually. Mechanical timing devices are not suitable for this purpose owing to the extremely short period of time involved (of the order of 0,02 second) and the powerful current used (usually several 100 amps). The employment of a relay valve controlled by a relaxation oscillation offers considerable advantages as it operates with perfect synchronism and can be readily and instantaneously regulated within wide limits. The design and operation of a timing device of this type are described below.

In addition to arc welding, two pieces of metal can also be bonded electrically by resistance welding in which a powerful current is passed through the metal. In this process the greatest resistance to the flow of current is encountered at the gap between the two surfaces, the heat generated at this point causing the metals to fuse together to give the desired bond. Usually the current is supplied to the two pieces of metal by means of more or less tapered electrodes, the weld covering an area with a diameter of only a few millimetres. Hence the term "spot-welding". To produce long seams, a series of welding-spots are required, to obtain which the electrodes are made in the form of rollers that are brought in contact with the metal surfaces to be bonded. The metal is then passed between the rollers at a speed determined by the distance required between the welding-spots, which in turn depends on the required mechanical strength and impermeability to liquids of gases. The present paper deals essentially with this method of seam-welding.

The heat generated at a welding-spot is determined by the strength of the current passed and its duration of flow. Investigations during recent years have shown that it is important for the current to be sufficiently powerful to allow it to pass through the metal for only an *extremely short period of time*, in order that the heat generated is restricted to the spot where it is required. The heating of the surrounding material, which is avoided by this means, is not only of no practical value but may also have a most deleterious effect on the quality of the weld, since it may cause oxidation and other undesirable chemical and physical changes.

The method of interrupting the flow of the welding current *periodically* signifies an important advance in this method of welding, as compared with a non-periodic interruption. In the first place it has led to a marked speeding up of welding, and secondly it has enabled such metals as stainless steels and aluminium alloys to be welded satisfactorily. In some cases it may be necessary to restrict the passage of the current to a few hundredths of a second, in other words to a few cycles of the alternating current, and it is evident that to give a satisfactory uniform weld a circuit breaker capable of performing this duty must operate in *perfect synchronism* with the mains supply and permit of such accurate adjustment that the intervals between the opening and closing of the associated circuit can be maintained absolutely constant. With the short times of current flow involved here, a difference of half a periode (0,01 second) either way is already sufficient to produce a marked alteration in the amount of heat produced. Furthermore, as the primary current of the transformer is several 100 amps (the secondary current being 1000 to 10000 amps at 3 to 10 volts), it is apparent that a mechanical device is quite impracticable, especially as it would be exposed to the most severe wear.

A more satisfactory and more efficient method for the synchronous opening and closing of the circuit is obtained by means of *relay valves*. These are gas-filled hot-cathode rectifiers with control grid; the ignition voltage of such valves can be adjusted by means of the grid voltage, as shown by *fig. 1*, the characteristic for Philips relay valve DCG 5/30. It will be noticed that at positive grid voltages exceeding 12 volts the

ignition voltage is low (<100 volts), whereas in the case for instance of —2 volts grid voltage the valve ignites only at 11000 volts anode voltage.

These relay valves render it possible, by means of certain circuits (see below) to close the current

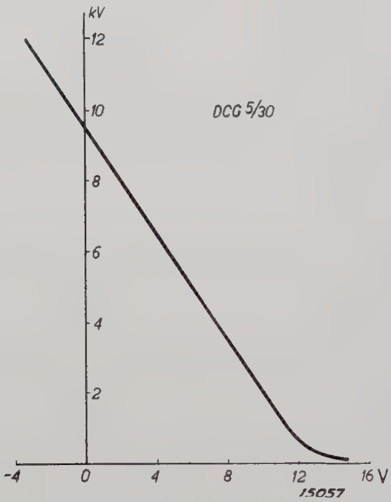


Fig. 1. Characteristic of Philips Relay Valve type DCG 5/30: Ignition voltage as a function of grid voltage.
Principal data: Max. peak inverse voltage 12000 volts
Max. anode current peak value, 25 amps
Max. anode current mean value, 6 amps

for any desirable number of cycles (x = 1, 2, 3, ...) and to open it for any other number of cycles (y = 1, 2, 3, ...), and this sequence x+y to be repeated periodically. The values of x and y can be varied independently of each other within wide limits. The principal advantages of a timing device of this type are:

1. Absence of all moving and revolving parts, no wear or noise;
2. Perfect synchronism with the mains supply;
3. Ready and instantaneous regulation of time intervals x and y;
4. The value of x can be reduced to a single cycle (0,02 second);
5. Uniformity in operation in any setting when once made.

Fig. 2 shows the various circuits making up the timing device, and which consist essentially of the three following:

A. The oscillating circuit;
B. The time-delay circuit;
C. The interrupter circuit;

these circuits are also shown separately and slightly simplified in figs. 3, 7 and 5.

The primary circuit of the welding transformer (T_1, *fig. 3*) includes the primary winding of a transformer (T_2), whose secondary winding is connected to the cathode and anode of a relay valve (M_1). Transformer T_3 serves for heating the cathode of valve M_1. When the potential difference between the grid and the cathode of M_1 reaches such a value that the valve passes current, transformer T_2 is shorted [1]), practically the whole of the mains voltage is applied across the terminals of T_1 and welding takes place. The grid of M_1 is now given a negative potential sufficiently large to prevent ignition of the valve: the secondary circuit of T_2 remains open, and only the weak magnetising current flows through the primary circuit; the welding current is then practically zero. A grid potential of $-V_g$ volts (e.g. derived from a battery) is sufficient to prevent ignition of the valve. What potential difference must be applied to the grid between the points 1 and 2 (fig. 3) so that the primary current can flow for a single cycle (x=1) and be cut off for y cycles (y being integral)? It follows from the above that this is obtained by imparting to the grid a positive potential impulse every (1+y) cycles, at the instant the anode becomes positive with respect to the cathode. We therefore require a potential of the

[1]) This applies only for one direction of the secondary current, but for the primary current this has practically the same effect as a complete short-circuit (cf. e.g. P. Lenz, Archiv für Elektrotechnik 27, 497, 1933).

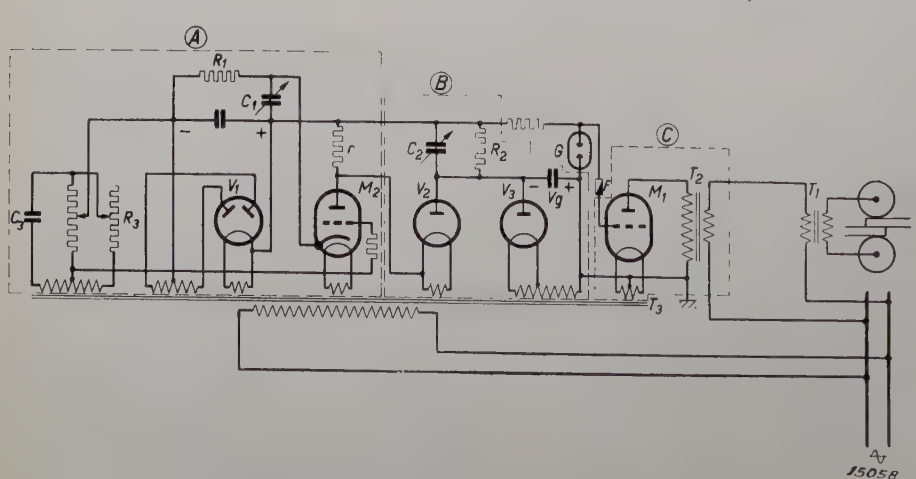


Fig. 2. Circuit diagram of timing device for seam welding.
T_1 = Welding transformer.
A = Oscillating circuit (see fig. 5).
B = Time-delay circuit (see fig. 7).
C = Interrupter circuit (see fig. 3).

form shown in *fig. 4*, i.e. an alternating voltage with a fundamental frequency $1/(1+y)$ times the mains frequency. Such demultiplication of the frequency may be conveniently obtained by means of relaxation oscillations [2]), which brings us to the oscillating circuit shown in *fig. 5*.

A small relay valve (M_2) of low output is connected in parallel with the condenser C_1, which

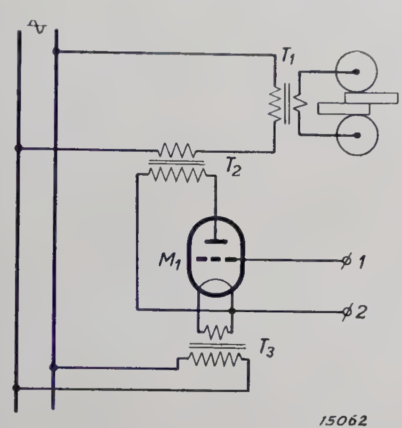


Fig. 3. Interrupter circuit (cf. "C" in fig. 2).
T_1 = Welding transformer.
T_2 = Series-transformer.
T_3 = Filament heating transformer.
M_1 = Main relay valve.
Grid (1) is negative with respect to cathode (2): the anode current of the valve is blocked and only no-load current flows through the primary circuit of T_2. Grid (1) is given a potential causing ignition of the valve: transformer T_2 is shorted and practically the whole of the mains voltage is applied across the welding transformer T_1.

is slowly charged from a source of direct current through a high resistance R_1 after the circuit is closed by the switch; the anode voltage, which is equal to the condenser voltage, therefore increases. As the potential of C_1 increases, there is a decrease of the voltage drop at R_1, which drop serves as negative grid voltage for valve M_2; after a certain time the valve ignites, the condenser is rapidly discharged through the valve and the small resistance r. This cycle then starts all over again. A free relaxation oscillation of this type has a frequency proportional to $1/R_1C_1$, although it can be very readily synchronised with a higher or lower harmonic of any other frequency introduced into the system. This is illustrated in *fig. 6*: anode and condenser voltage with respect to the cathode K show an exponential trend (A, C_1). The trend of the critical grid voltage (dotted line g) has been deduced from this by means of the characteristic, i.e the grid voltage required for ignition at the anode voltage in question. Actually the grid voltage G consists of the voltage-drop across R_1 (V_{R_1}) with the superimposed A.C. voltage V_S. Ignition takes place the moment the actual grid voltage exceeds the critical one, i.e. at the point of intersection of the curves G and g. As this point of intersection will always be situated near the peak of V_S, only such conditions will occur at which an integral number (1, 2, 3 ...) of cycles of the frequency of

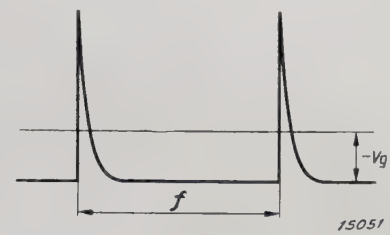


Fig. 4. Required voltage waveform between terminals 1 and 2 (fig. 3) in order to obtain welding-spots during a single cycle at intervals of y cycles.

the synchronising voltage elapses between two successive ignitions. The frequency of the free relaxation oscillation will therefore adapt itself to that of the adjacent lower harmonic (1/1, 1/2, 1/3 ...) of the imposed mains-frequency. It is, for instance, sufficient to apply to the grid circuit a low-voltage 50-cycle alternating current (fig. 5) in order to

Fig. 5. Oscillating circuit (simplified) (Cf. "A" in fig. 2).
C_1 = Variable condenser.
R_1 = Charging resistance.
r = Discharging resistance.
M_2 = Relay valve.
T_3 = Transformer to furnish a potential of mains frequency at the grid of M_2.
Valve M_2 is ignited with a frequency which is a sub-harmonic of the mains frequency. The degree of frequency demultiplication is determined by the product C_1R_1. Circuit C_3R_3 permits the phase displacement to be varied between the relaxation oscillation obtained and the mains.

limit the possible frequencies of the relaxation oscillations to 50, 25, $16^2/_3$, $12^1/_2$ and 10 cycles, etc. If to the capacity of C_1 values are given at which

[2]) Cf. e.g. B. van der Pol, Phil. mag. **2**, 978, 1926, and B. van der Pol and J. van der Mark, Frequency Demultiplication, Nature **120**, 363, 1927.

the free relaxation frequency would be in the neighbourhood of these fractions of the mains frequency, a current impulse will flow through the resistance r (fig. 5) every 2, 3, 4 or more periods of the mains supply. The potential at r, combined with the

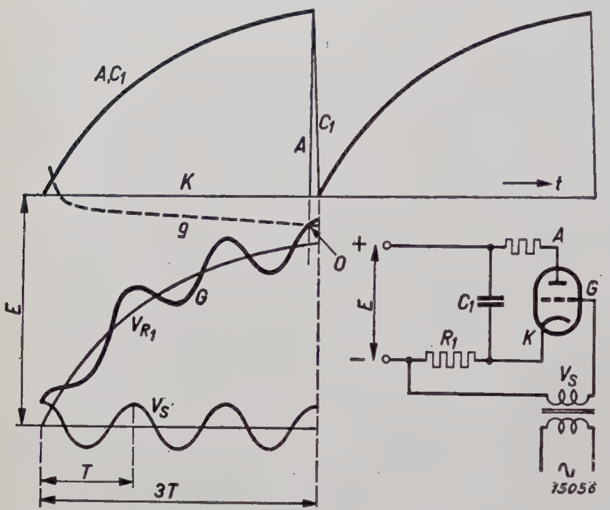


Fig. 6. Diagram of a free relaxation oscillation synchronised with a lower harmonic (in this case $^1/_3$) of an imposed A.C. voltage.

battery voltage $-V_g$, then fluctuates as shown in fig. 4. The condenser C_3 and resistance R_3 (fig. 5) permit the phase displacement between the mains voltage and the grid potential of M_2 to be adjusted in such a way that M_2 is ignited exactly at the instant the anode of M_1 becomes positive. The phase displacement requires adjustment only once and remains constant.

By connecting terminals 1 and 2 in fig. 5 with terminals 1 and 2 in fig. 3, an arrangement is obtained which allows current to be passed through the associated circuit for one single cycle at intervals of 2, 3, 4 or more cycles. For some purposes this duration of current flow may be too short, and one would like to be able to prolong it as required to 2, 3, 4 or more periods, retaining at

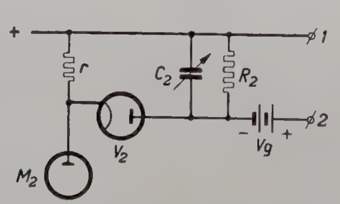


Fig. 7. Time-delay circuit (simplified) (cf. "B" in fig. 2). This circuit which is made up of a variable condenser C_2, a resistance R_2 and a valve V_2, serves for prolonging the interval during which welding current is flowing.

the same time a suitable interval with no current-flowing. This can be readily achieved by inserting a time-delay circuit between the circuits C and A in figs. 3 and 5, which will prolong as required the time the positive impulse is applied to the grid of M_1. A circuit of this type is shown in *fig.* 7; it has a condenser C_2 in parallel with the resistance r (fig. 5) which is charged the instant

Fig. 8. Front view of apparatus. On the left is the knob for controlling the "on + off" cycle (x+y) which is variable between 1 and 75 periods of the 50-cycle current, and on the right the knob for controlling the "on" interval (x); in the middle at the top is a pilot lamp, and below the switch for the auxiliary circuits.

the valve M_2 becomes ignited and is discharged slowly through the high resistance R_2 (a rapid discharge of C_2 through r is prevented by the valve V_2). By increasing the capacity of C_2 (or the resistance R_2) the interval during which the grid of M_1 remains positive with respect to the cathode can be increased as required, this interval corres-

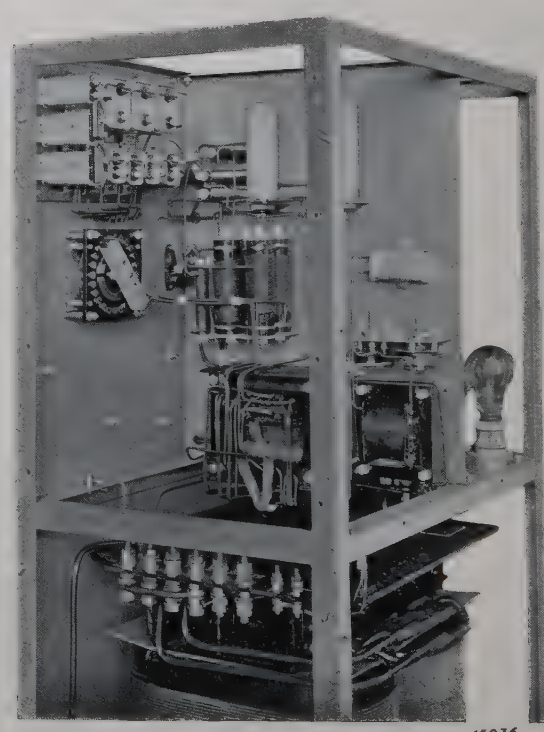
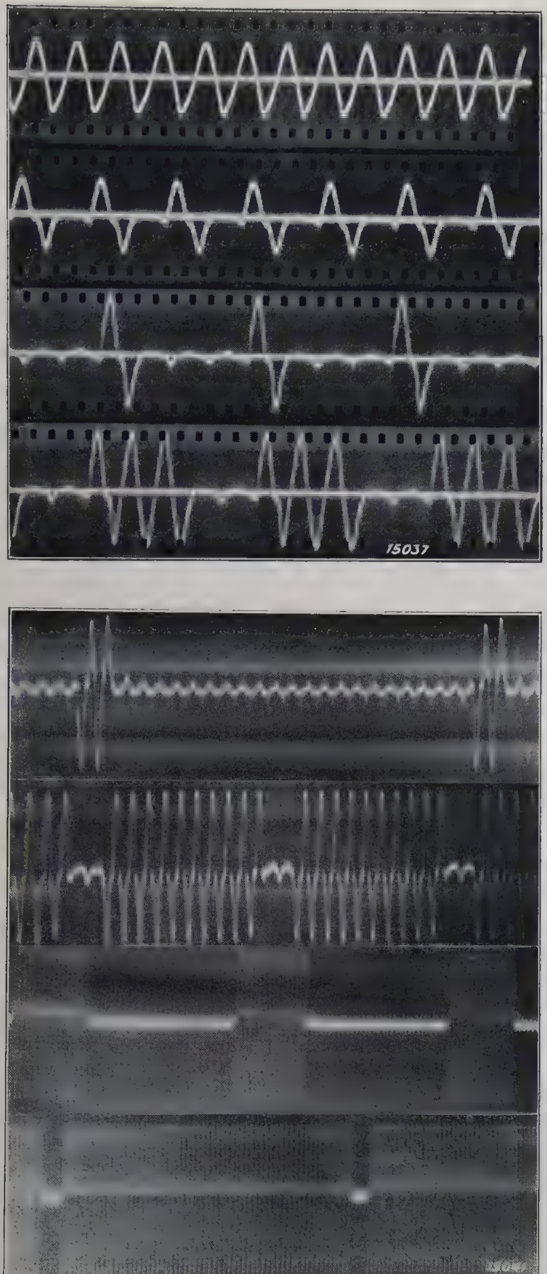


Fig. 9. Interior view of apparatus. Below, the series-transformer (T_2), on the left at the top the condensers and a step switch. The valves are on the right hand side behind the partition.



x	y
1	0
1	1
1	3
3	2

x	y
2	22
10	2
16	32
62	4

Fig. 10. Oscillograms of the primary current: Circuit closed for x cycles, and opened for y cycles.

ponding to the number of cycles x the welding-current flows. The apparatus thus has two control knobs by means of which the capacities of C_1 and C_2 can be varied: With C_2 x is adjusted and with C_1 the whole sequence x+y.

Returning to the complete diagram (fig. 2), which incorporates the individual circuits shown in figs. 3, 5 and 7, it is seen that the batteries in the latter have been replaced by rectifiers (valves V_1 and V_3) which are provided with condensers for smoothing the rectified voltage. The apparatus is protected against the high tension of the transformer T_2 on the one hand by earthing the cathode of M_1, and on the other hand by the fuse F and the the rare gas cartridge G (fig. 2). In the event of a short-circuit between the grid and anode of valve M_1, the cartridge G ignites and blows out the fuse F, thus disconnecting the valve from the rest of the circuit.

An apparatus of the type described here is shown in *figs. 8 and 9*. The controls referred to above are mounted on the front panel. Transformer T_2 is accommodated in the lower part of the housing, and the relay valves M_1 and the auxiliary circuits in the top part. A number of oscillograms of the primary current obtained with this apparatus are reproduced in *fig. 10*; it is seen that there is perfect periodicity in the opening and closing of the circuit in synchronism with the mains supply. These curves also show that a wide variety of settings can be obtained with this apparatus.

The above description brings out the many practical advantages of a relay-valve timing circuit as compared with mechanical devices.

AN EXPERIMENTAL TELEVISION TRANSMITTER AND RECEIVER

By J. VAN DER MARK.

Summary. On the occasion of the erection of a television transmitter at the Philips Laboratory, some of the main principles of modern television are discussed. The circuit and components of a modern television transmitter and receiver are described with special reference to the Philips experimental unit.

Principle of Television

The human eye is a very complex and sensitive organ, whose optical mechanism functions briefly as follows: The crystalline lens of the eye produces an image of the field of view on the retina which is made up of a very large number of minute lightsensitive cells. Each of these cells through its own nerve filament communicates to the brain the stimulus it receives from the amount of light falling on it, and from the sum-total of the stimuli received by it the brain builds up the image seen by the eye.

In the human eye Nature has provided us with the basic principles of television fully worked out; also in televising the area of the picture to be transmitted is resolved into a large number of small elements or cells (*fig. 1*). Each of these elements is given a number and the light value of each element is telegraphed to the receiver in sequential order. Exactly as at the transmitter, the picture surface at the receiver is also resolved into elements which are numbered in the same way, and each element is given the light value telegraphed for its particular number. In this way

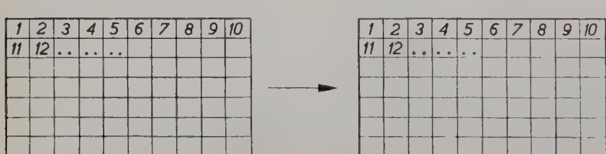


Fig. 1. Principle of television. The surface of the picture to be televised is resolved into a number of small elements which are numbered in succession. The brightness of each individual element is telegraphed. At the receiver where the picture surface is subdivided into similar elements each element is given the brightness transmitted for its respective number, so that the received picture exactly reproduces the original.

the picture reproduced at the receiver is the same as that transmitted by the sender.

In the eye every element of the picture in the transmitter (cell of retina) has its own conductor (optic nerve filament) to the receiver (brain), and the light values of all elements are telegraphed simultaneously. In television this simultaneity naturally cannot be effected, as only one conductor (a single carrier wave) is available for all picture elements, so that the separate light values must be telegraphed in succession. In consequence television technique is rather complex, as may be exemplified by a simple calculation. To obtain a picture of satisfactory quality, the area of a picture measuring 4×4.8 in. must be resolved into about 40000 elements. In televising moving pictures, it is necessary, as in cinematography, to send a sufficient number of pictures per second, at least 25, in order to produce a connective image on spectator's eye. Thus, only 1/25th of a second is available for the transmission of each picture, in other words each second the light values of $25 \times 40000 =$ 1,000,000 elements of the picture must be telegraphed [1]).

Conversion of a Picture into a Modulated Radio Wave. Resolution of the Picture into Elements or Cells

Both at the transmitter and receiver the picture is resolved into a series of elements or cells by "scanning" it with a beam of electrons furnished by a cathode ray tube. The scanning spot at which the electronic beam strikes the surface of the picture describes a path on this surface of the type shown in *fig. 2*. This path is made up of a series of nearly horizontal lines packed close together, the beam passing over these lines in

[1]) This is aptly brought out by the following example: For some years facsimile and picture telegraphy has enabled pictures to be transmitted by telegraphy, the transmission of a single picture taking from 10 to 20 seconds or even longer. In the Melbourne Air Race in October, 1934, a film was made of the arrival of the winners at Melbourne and was transmitted to London. This short film, which was on exhibition at London cinemas on the same day already, took a $^3/_4$ minute to project, while the time of transmission from Australia was about 6 hours. In television the same transmission must be completed in a $^3/_4$ minute.

succession. When the beam reaches the end of one line, it jumps to the beginning of the next line, scans it in exactly the same way and so on over the whole picture, until it arrives at the end of the last line. Then it flies back to the beginning of the first line and goes through the same sequence of operations again. During scanning, the scanning beam measures the brightness of each element of the picture as described in the next section. The beam is guided along its scanning path by two voltages which deflect the beam to varying degrees simultaneously, each voltage fluctuating with a saw-tooth voltage-time diagram as shown in *fig. 3*. The slow voltage controls the scanning motion in the vertical direction with a frequency equal to the number of pictures per second, while the fast voltage controls the motion in the horizontal direction with a frequency equal to the product of the number of pictures per second and the number of lines in the picture.

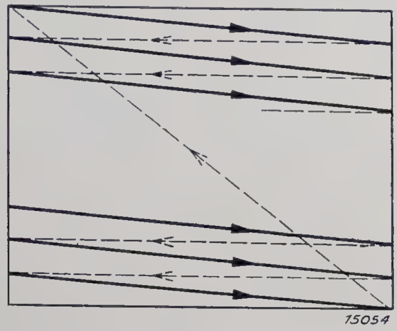


Fig. 2. The numbering in fig. 1 is replaced by "scanning" the picture in a definite sequence. The path of the scanning spot shown here determines the order in which the various elements are telegraphed.

In order to reassemble the picture at the receiver from the elements in the same manner, as it was resolved at the transmitter, the electron beam in the cathode ray tube of the receiver must at every moment occupy exactly the same position relative to the picture as the electron beam of the transmitter, i.e. the scanning sequence in the receiver and transmitter must be completely synchronised. This is realised by means of two distinct types of synchronising signals which are radiated from the transmitter at the end of every line and each picture respectively. We shall return to this point later.

The modulation of the light value when scanning a horizontal line may be regarded as equivalent to a resolution into a definite number of elements. If the picture is a square and has the same sharpness both horizontally and vertically, the number of these elements must be equal to the number of lines N in the whole picture. Usually rectangular pictures with sides in a ratio of 6 : 5 are televised [2]). The total number of elements in the picture is then 1.2 N^2. The number of picture elements to be transmitted per second, which determines the maximum modulating frequency of the radio wave required for televising the picture, is then 30 N^2 with a picture frequency of 25. In this way very high frequencies are soon reached. Since an alternating current of p cycles per second already corresponds to 2p alternations per second of light and dark, the required modulating frequency can be halved, so that with 180 lines the maximum modulating frequency is 500,000 cycles and with 450 lines 3,000,000 cycles.

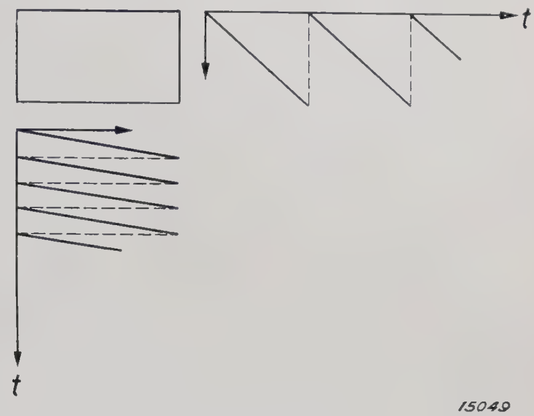


Fig. 3. Composition of the two motions of the scanning beam. A deflecting voltage with a saw-tooth time diagram controls motion along each line (left), while a similar voltage (right) N times slower (N being the number of lines in the picture) controls the beam motion in such a way that it does not incessantly scan the same line but passes along the N lines in succession and then flies back to its starting point again.

As already stated, television signals are transmitted in the same way as microphone signals in broadcasting by modulation of a carrier wave whose frequency must be considerably higher than the modulating frequency. For televising it is therefore necessary to use a carrier wave in the ultra short-wave range between 7 and 5 metres.

This very short wave, however, has a particular drawback. Contrary to broadcasting waves of several 100 m in length these waves do not propagate along the curved surface of the earth. They can therefore only be received within a radius which barely exceeds the distance at which the transmitting aerial is still in sight of the receiving aerial [3]). To make this area as large as possible, the

[2]) This is the usual size ratio of sound-film pictures.

[3]) Recently these waves have been detected for short intervals also at greater distances, but reception has been so patchy that satisfactory transmission to points beyond the visible horizon is quite impracticable.

aerial must be suspended from very high masts. In the case of the transmitter at Eindhoven, the primary aim has not been to obtain a range of reception as large as possible; the aerial has therefore only been made about 150 ft. high and is fixed to a small mast on the roof of one of the works buildings. The Eindhoven transmitter operates on a wave-length of about 7 m and has a maximum output of about 400 watts; it has been designed for a maximum modulating frequency of about 3,000,000 cycles and can therefore televise pictures of the finest screen yet attained.

Conversion of Light Values into Voltages with the Iconoscope

How are the light values, registered by the electron beam on scanning the picture elements, converted into a modulating voltage? The apparatus here used for this purpose, is the iconoscope which was developed by Zworykin. It here fulfils the same function as the human eye in the seeing mechanism.

This apparatus (*fig. 4*) consists of a cathode ray tube, which, in addition to the usual hot cathode, the anode and the deflector system in part K, also has a photo-electric plate P prepared in a special manner mounted in place of the usual fluorescent screen. The picture to be televised is projected on to this plate by means of an ordinary photographic lens. The whole arrangement, comprising the iconoscope with the attached optical system for projecting the picture on the plate P, may be termed a "television camera". Plate P, which may be regarded as the retina in the eye of the transmitter, is made of very thin non-conducting material (cf. fig. 4), which has a uniformily-distributed mosaic of separate cells in the form of drops of metal on the illuminated side. These cells are insulated from each other and have photoelectric surfaces. The number of these cells is so great that several fall within the area covered by the scanning beam. On the back the insulated plate P is covered with a continuous conducting layer, which with the metal cells on the upper surface forms a corresponding number of minute condensers from which current can be taken at the outside.

As soon as the scanning spot strikes a cell, the latter acquires a negative charge from the beam up to a certain maximum value; this means that the associated condenser gets a definite potential. The beam now moves onward and only returns to this cell again after having scanned the whole picture. In the meantime, the photo-electric cell emits photoelectrons under the action of the incident light and thus looses a part of its charge, this diminution being proportional to the light value of the picture at the respective point. When

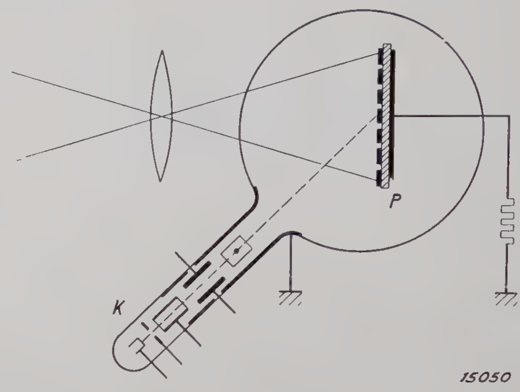


Fig. 4. The iconoscope. In a cathode ray tube which contains the usual components in part K (hot cathode, anode and deflection systems), the fluorescent screen is replaced by a photo-electric plate P (the "retina") prepared in a special way, on to which the picture to be televised is projected.

the scanning spot again reaches the cell, the latter's depleted stock of electrons is immediately replenished until the same maximum charge is restored as it possessed at the outset. At the instant this occurs, a charging current proportional to the brightness of the picture at this particular point flows from the outside to the condenser. A potential is hence produced at the resistance R (fig. 4) in the external circuit of the iconoscope which at each instant is proportional to the light value of the various picture elements in the sequence they are scanned. This potential is now amplified and serves for modulating the radiated carrier wave.

The great advantage of the iconoscope as compared with other systems, such as for instance Nipkow's disc, is its high sensitivity: while in other cases the brightness of each picture element must be measured in the extremely short period the scanning spot is in contact with the element, in the iconoscope the light at each such point can act as a stimulus during the far longer period between successive scanning moments and the effect produced is stored as an electric charge in the individual condensers. Only by means of this enormous gain in sensitivity is it at all possible to televise ordinary daylight scenes without spotlights, etc.

Films are transmitted by a somewhat different process, as here a sufficient interval must be provided to allow for the motion of the film. To enable the television camera designed for out-door scenes to be used without alteration also for films, the film is only illuminated during the period of the synchronising impulse at the end of each picture

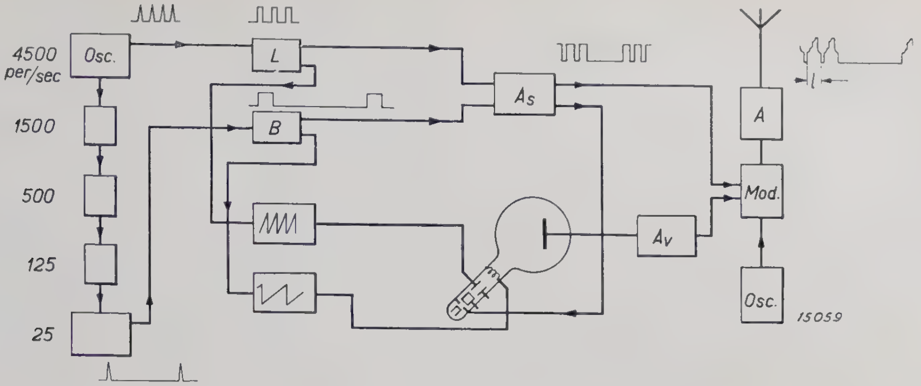


Fig. 5. Circuit diagram of television transmitter (simplified). In the top left hand corner is the oscillator which generates the line impulses of $25 \times 180 = 4500$ cycles (with 450 lines in the picture this value would be $25 \times 450 = 11250$ cycles). In the stages immediately below, this frequency is demultiplied until the picture frequency of 25 per second is reached. From these two types of impulses the line and picture synchronising signals (rectangular voltage wave-form) are generated in circuits L and B respectively. These have firstly to synchronise the two relaxation voltage units which control the movement of the iconoscope scanning beam, and secondly they are amplified in As and used for modulating the carrier wave generated by the oscillator in the bottom right hand corner. The voltage fluctuations furnished by the iconoscope are amplified in the video-frequency amplifier Av and also modulated on the carrier wave. A is the last amplifier for the modulated carrier wave.

scanning cycle. As the film also can be illuminated with a greater light intensity according to requirements, the short period of illumination is not a drawback. For the same reason, however, the iconoscope offers no pronounced advantage in this case.

The Transmitter. Synchronising Signals

We shall now briefly review the circuit and components of the television transmitter. In the first place the voltages for the synchronous control of the scanning beams must be generated.

An oscillator (in the left hand top corner of the diagram in *fig. 5*) generates relaxation oscillations of line-frequency, i.e. 25 N (thus with $N = 180$, a frequency of 4500 cycles). This frequency is demultiplied in successive stages until the picture frequency of about 25 cycles is obtained. Frequency demultiplication is very simple with relaxation oscillations [4]).

The line and picture impulses [5]) generated do not yet possess the voltage wave-form required for the synchronising signals, but these signals can be obtained quite simply from them, exactly as they have to be modulated on the radiated carrier wave: These signals are right-angled voltage impulses of specific duration. The duration of the signal for each line is about 5 per cent of the time required for scanning a line; the synchronising signal for each picture is equal to the scanning time of several lines. As a result a width of several lines is lost at the bottom of the picture; but even if hence say only 170 lines are contained in the visible picture instead of 180, we must still take $N = 180$ when calculating the line frequency.

Control of Scanning Beam

Each of the two synchronising signals controls one of the relaxation voltage units, which together provide the components for controlling the motion of the scanning beam as already shown in fig. 3. Each voltage unit consists essentially of a condenser which is charged by a constant current (thus giving a potential which increases linearly with the time), and a discharge tube which is ignited by the corresponding synchronising signal so that the condenser is discharged (the potential rapidly drops to zero). The potential generated is applied to the deflecting system of the cathode ray tube and causes the scanning beam to move to and fro in the manner required.

While with Nipkow's disc, the number of lines in the picture is invariable, as it is equal to the number of perforations in the disc, it is comparatively simple with the iconoscope to adapt a transmitter for televising different numbers of

[4]) The properties of relaxation oscillations, particularly for frequency demultiplication, have for some years been the subject of close investigation in this laboratory. Cf.e.g. B. van der Pol, Phil. Mag. **2**, 978, 1926, and B. van der Pol and J. van der Mark, Nature **120**, 363, 1927.

[5]) In televising films, the frequencies of the line and picture impulses generated must also be in a fixed ratio to the frequency of the local mains supply, as in film projection a mains-fed synchronous motor is usually employed. The picture synchronising signal (period of illumination) must always coincide with the moment the film is stationary. This supplementary synchronising with the mains will not be further discussed here.

lines per picture. To do this it is only necessary to alter the velocity of the component motions of the scanning beam by adjusting the relaxation voltage units and the synchronising signals. It is proposed to modify the transmitter, which is now under test, on these lines at some later date and to carry out experiments with the various systems of transmission.

In the iconoscope the photo-electric plate (the picture surface) is at an angle to the scanning beam, so that the picture can be projected vertically on it (see fig. 4). This requires certain additional corrections in the relaxation voltages generated in order to scan properly the picture with the electron beam.

Amplification of the Modulated Voltage

The small voltage fluctuations furnished by the iconoscope must be amplified before they can be modulated on the radiated carrier wave. The "video-frequency" amplifier provided for this purpose (A_V in fig. 5) has to perform a far more difficult task here than the "audio-frequency" amplifier commonly used for sound reproduction in broadcasting. For while in television the voltage wave-form at the receiver must be exactly similar to that at the transmitter, in broadcasting if we regard the modulating voltage as resolved into all its component frequencies (its Fourier spectrum) the various frequencies are permitted to reach the loudspeaker with a larger or a smaller phase displacement: in music we are unable to detect differences in phase. In television, however, a phase displacement of the component frequencies would completely destroy the original voltage wave-form and fluff the picture received. It follows therefore that the transit times of each frequency through the amplifier must be equal within certain limits. The frequencies in question here cover a spread from a few cycles to more than 3000000 cycles, as already calculated above. Again in this respect there is a radical difference to ordinary radio amplifiers, as in broadcasting the highest modulating frequencies do not exceed 5000 cycles.

By using various special circuits it has been possible to construct amplifiers which satisfy the above requirements for televising 25 pictures per second and 450 lines per picture. The voltages amplified in this way, together with the synchronising signals amplified separately by A_S in fig. 5, are now used for modulating the carrier wave. The radiated signal is of the form shown in the right hand top corner of fig. 5, where l corresponds to a line in the picture.

In addition to the components already mentioned the transmitter is also equipped with a number of auxiliary units, such as oscillographs to control the relaxation voltages, and for further control of the modulated voltages a receiver in which the radiated picture is reassembled. Sound is radiated by a separate apparatus on an adjoining wave length, which facilitates tuning of the receiver. Reference to these points must be dispensed with here.

The receiver

In the receiver (circuit shown in *fig. 6*) a picture has to be reassembled from the incoming signals. This is done in a cathode ray tube B of which a modified form has already been met with in the television camera. The tube in the receiver is, however, of the standard form as employed in cathode ray oscillographs, i.e. with a fluorescent screen F on which the electron beam inscribes the image in the usual way. This beam is again controlled by two relaxation voltage units in the same way as in the transmitter, so that the light spot on the screen describes a path as shown in fig. 2. At the same time the intensity of fluorescence is varied by modulating the intensity of the scanning beam

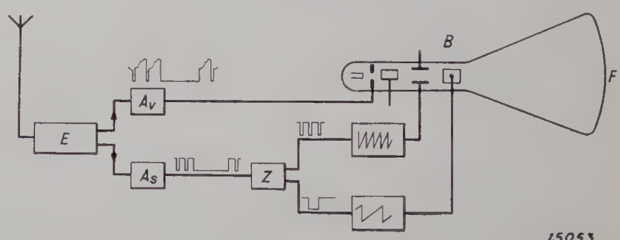


Fig. 6. Circuit diagram for television receiver. The television signals received and rectified at the receiver E are amplified in the video-frequency amplifier Av and applied to the control grid of the cathode ray tube B, after the synchronising signals have been filtered out in As by means of their particular amplitude. In the two filter circuits Z the (short) line and the (long) picture synchronising signals are separated from each other and passed to the respective relaxation voltage units which control the motion of the scanning beam. The picture is produced on the fluorescent screen F.

by means of a control grid which functions in exactly the same way as the grid in a radio valve. The incoming picture signals are applied to the control grid, so that the brightness of the fluorescent spot fluctuates with the variations in light value registered on the original picture by the scanning beam of the transmitter. In this way the same picture as transmitted is reproduced on the fluorescent screen [6]).

The received signals are amplified by a video-

[6]) The cathode ray tube will shortly be the subject of further separate articles in this journal.

frequency amplifier (A_V) similar to that used in the transmitter. They also include the synchronising signals which here have to maintain the displacements of the scanning beams of the receiver and transmitter in perfect synchronism. These signals have been modulated on the carrier wave in a certain manner, so that they can be separated from the picture modulation by an amplifier (A_S) responding to specific amplitudes only. Exactly as in the transmitter, the saw-tooth motion of the receiver scanning beam (fig. 3) is obtained by means of oscillating circuits, which generate the requisite type of relaxation oscillations having a frequency which in unconstrained vibration is already close to the required frequency and which is corrected to obtain the right rhythm by the synchronising signals which come in at regular intervals. By using two filter circuits (Z), of which one responds to only short potential impulses and the other to only long impulses, the (short) line-synchronising signals can be separated from the (long) picture-synchronising signals and passed separately to the corresponding relaxation voltage units.

Receivers constructed on these principles were evolved some time ago in this laboratory and have operated with complete satisfaction. *Fig. 7* reproduces two photographs of televised pictures (180 lines) which show the quality of reproduction already here attained.

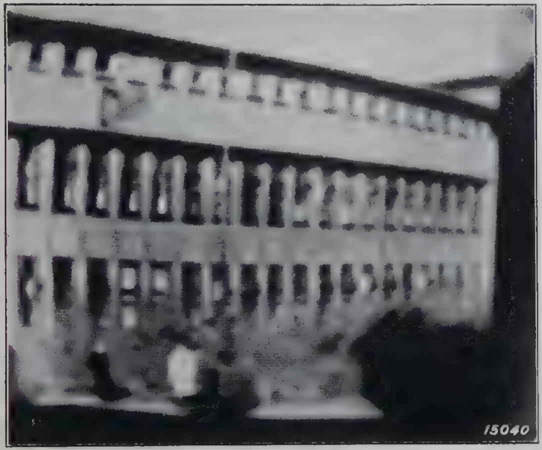


Fig. 7. Two television pictures (180 lines) produced with the new television plant at this laboratory.

a) An out-door scene (without artificial lighting). b) A studio-portrait.

THE LOUDSPEAKER AND SOUND-AMPLIFYING INSTALLATION ON THE T.S.S. "NORMANDIE"

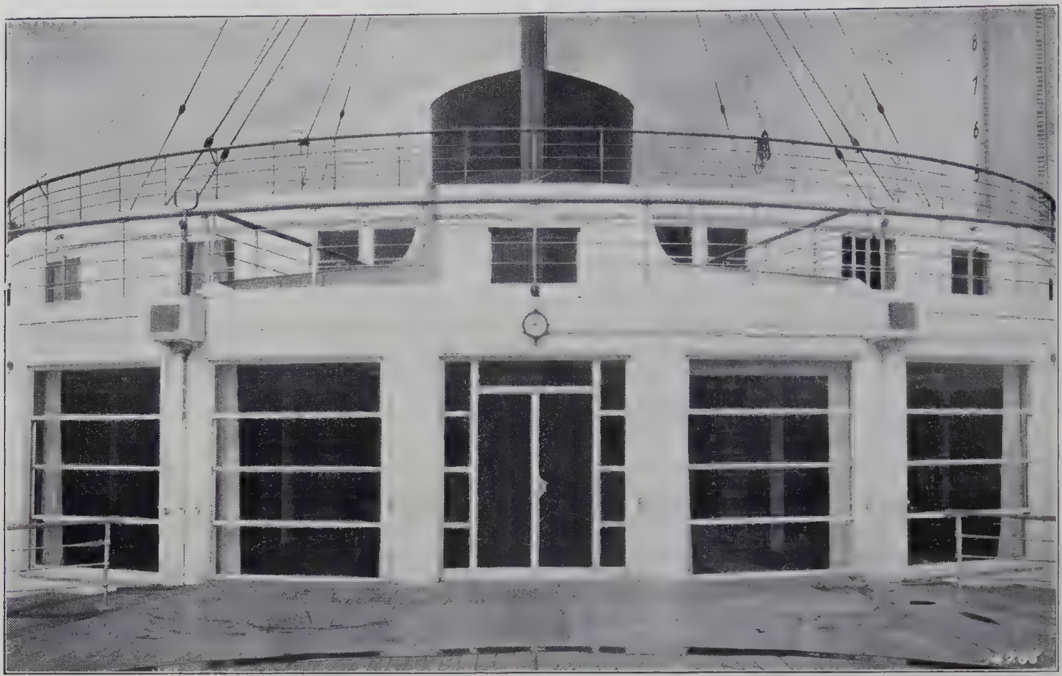


Fig. 1. Watertight loudspeakers on the fore-deck.

With the steady perfection in the efficiency of microphones, amplifiers and loudspeakers in recent years, sound-amplifying installations have come more and more into favour for the transmission of speech and music and their amplified reproduction without loss of naturalness.

Installations of this type have recently also been carried out in ships. For the TSS. "Normandie", Philips has evolved and constructed a very comprehensive loudspeaker and sound-amplifying installation, a description of which will give some idea of what has already been achieved in this direction.

Seventy-four loudspeakers are distributed throughout the vessel. These are of watertight construction where necessary (*fig. 1*), being protected against sea-water and rain by the addition of weatherboards which in no way affect the radiation of sound.

In the passenger saloons the loudspeakers are installed as inconspicuously as possible; in fact in the 1st Class saloon it is almost impossible to detect that the gilt rosette over the escutcheon at the entrance hides a loudspeaker horn (*fig. 2*). In the 1st Class smoking saloon, the loudspeakers are fixed behind a lamp over the upright wall fittings (*fig. 3*); in the winter garden the loudspeaker is recessed in the wall under the clock (*fig. 4*), while in the dining room the speakers are hidden from sight in the ceiling panels. At all points where "acoustic reaction" is likely to cause interference (i.e. the sound radiated from a loudspeaker can again be picked up by the transmitting microphone) when broadcasting speeches and addresses, etc., the particular loudspeakers likely to cause trouble can be switched off.

The loudspeaker installation on the TSS. "Normandie" is designed for the following purposes:

- Transmission of musical programmes by the ship's orchestra.
- Transmission of gramophone records, e.g. organ music for religious services in the chapel.
- Transmission of speeches and news.
- Transmission of radio programmes.
- Transmission of religious services in the chapel to other parts of the ship.
- Transmission of orders from the bridge to the passenger decks in the event of accident or danger.

For the transmission of music and speech, microphones are installed in the chapel, the 1st Class dining saloon, the large 1st Class saloon, the theatre, in the grill room and on the bridge. The bridge microphone has precedence over all other microphones, the captain being always in a position to address every one of the 2000 passengers from the bridge. Oral communications regarding landing arrangements, explanations of delays, notices of

festivities, etc., can now be transmitted to all passengers from the bridge much quicker than by the method employed hitherto of posting up notices at various points in the vessel. Loudspeakers are also provided on the boat deck, so that orders and instructions can similarly be issued during boat drill.

Should the space available in the chapel be insufficient to accomodate the whole of the congregation, arrangements can be made for the Tourist Class passengers to remain in their saloon and receive the service through the medium of the loudspeakers installed there. These speakers are connected to the microphone in the chapel through one of the amplifiers.

The theatre which has 400 seats is not large enough to accommodate all the First Class passengers, but with the aid of the loudspeaker

Fig. 2. 1st Class saloon, with loudspeaker built in over the entrance.

installation it is possible to transmit theatrical productions, musical recitals and other stage productions to all those passengers unprovided with seats.

The ship's orchestra plays alternatively in the dining room and in the grill room, both of which are provided with microphones; the grill room can moreover be converted for dancing. For the reproduction and transmission of gramophone records, a playing desk with two turntables in a cardan suspension is provided so that the records remain perfectly horizontal also during the rolling of the vessel.

To ensure maximum reliability and continuity

Fig. 3. 1st Class smoking saloon, with loudspeakers built in over the entrance.

in the functioning of the whole equipment, all essential components, such as the amplifiers and the 3-kw D.C.-A.C. converters, have been duplicated. In addition to the two principal amplifiers, each of 350 watts output (the output can be reduced to 175 watts by cutting out two of the four last-stage valves), two smaller amplifiers, each of 20 watts, are also provided.

The 74 loudspeakers of 6, 10 and 20 watts are rated for 680 watts at full load. As a rule the loudspeakers will not be run all at the same time or all at their maximum power (the volume of each loudspeaker can be adjusted independently); a reduced amplifier output, e.g. 350 watts + 175 watts or 350 watts, will then prove sufficient to feed all speakers in operation. One of the 20-watt amplifiers is sufficient for transmitting a service in the chapel to one of the Tourist Class or Third Class saloons. By means of a switchboard in the amplifier room (see *fig. 5*), the 40 loudspeaker circuits terminating at the board can be connected to the 4 amplifiers (fig. 5, b, d and e) in various ways as required.

A simplified circuit diagram of the installation on the TSS. "Normandie" is shown in *fig. 6*.

All amplifiers have a maximum output voltage of 100 volts at normal full load. The cone coils of the electrodynamic loudspeakers must be built for a much lower voltage, and these are therefore provided with transformers to enable them to be connected to the standard 100-volts supply.

Owing to the comparatively high voltage and hence the low current intensity in the circuits, the voltage losses remain within reasonable limits in spite of the great length of the many conductors required on this large vessel. A still higher voltage

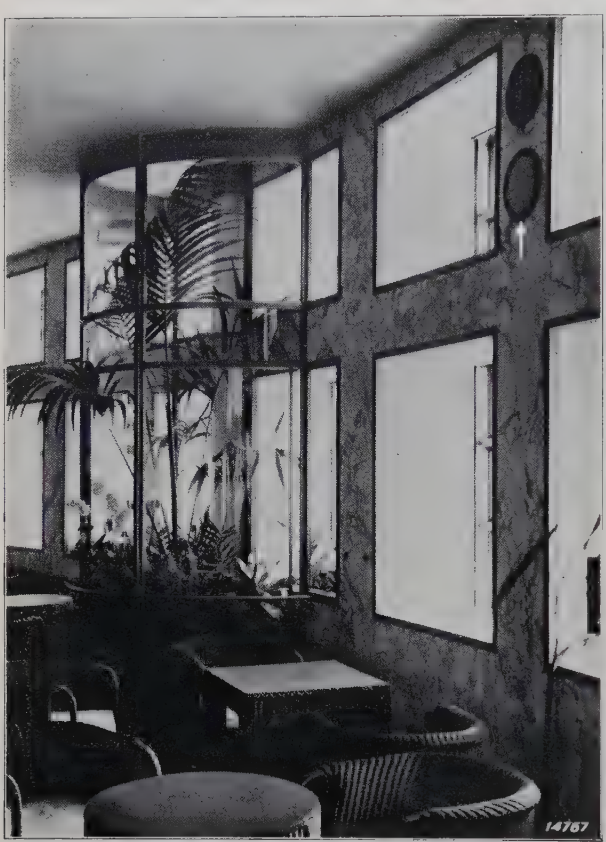


Fig. 4. Wintergarden with loudspeaker built in under the clock.

has not been chosen on account of the risk of accidents and because the capacity of the extensive cable system might then adversely affect the quality of reproduction.

When connecting one or more loudspeakers to an amplifier, it is necessary to take as a basis the principle that the rated consumption of the loudspeakers is equal to the rated output of the amplifier; furthermore, the total impedance of all loudspeakers must be such that they can actually take the output of the amplifier. To arrive at this adaptation, a number of tappings on the secondary winding of the output transformer may be useful. As commercial types of loudspeakers have very different impedance values, it may be very difficult or even impossible in some circumstances to obtain the required total impedance by merely connecting the loudspeakers in series or parallel. Frequently a number of loudspeakers are connected in series in order to avoid excessive current intensities and voltage losses. In power current practice complicated circuits of this type have long been abandoned, and it is now the practice to provide a constant voltage supply to which only apparatus rated for this specific supply voltage are connected in parallel.

This method has also been adopted by Philips for sound-amplifying installations. The amplifiers at complete modulation (i.e. at the highest possible voltage of the signal to be amplified) and on full load furnish an output of 100 volts. As already pointed out above, the loudspeakers are provided with transformers with ratios of transformation such that on connection to a 100-volt input the power absorbed is equal to that rated power for which the loudspeakers are built.

Thus it is unnecessary to sum the reciprocal values of the loudspeaker impedances, which constitute the load, in order to obtain the total impedance determining the correct adaptation. The problem of correct adaptation is now easier to deal with. For if the total rated consumption of the loudspeakers, which individually may have very different consumption ratings, is made equal to the rated output of the amplifier, one is assured that the amplifier will really give this output.

If the rated output of the amplifier is slightly exceeded by the rated consumption of the loudspeakers, this will not cause any appreciable

Fig. 5. Amplifier room.

a) Switchboard for the microphone circuits
b) Two 20-W amplifiers with impedance matching boxes below
c) Switchboard for the loudspeaker circuits
d) and e) Two 350 W amplifiers.

reduction in the output of the amplifier. Heavy overloading of the amplifier is however undesirable, since inter alia the voltage drop resulting therefrom is frequently accompanied by an increase

in the current intensity, which in the long run may e.g. damage the end-stage valves. On the other hand, there is no objection to a subnormal load, as long as the voltage does not rise too much that the loudspeakers become overloaded.

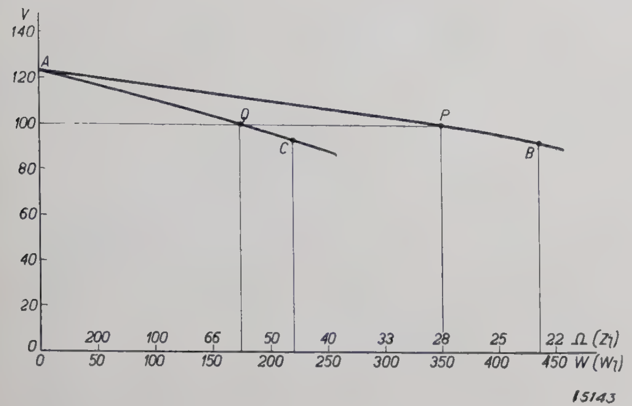


Fig. 7. Voltage curves of the amplifier as a function of the rated power consumption of the connected loudspeakers. The line A-B is for the 350-W amplifier at full output, and A-C for the same amplifier when set for supply of half the power.

In installations of this type where a fluctuating load has to be dealt with, the output voltage must not be too closely dependent on the load. This requirement is met by the Philips 350-watt amplifier as may be seen from *fig. 7* where the voltage is plotted against the power consumption of the connected loudspeakers. On no-load the voltage does not exceed 123 volts, which can do no harm to the Philips loudspeakers. In practice it is very unlikely that o n e loudspeaker only will be connected to the 350-watt amplifier; besides, the overload of the loudspeaker implied in this case will be audible only at the loudest passages of the music.

The permissible maximum load on the amplifier is shown in fig. 7 by the points B and C respectively.

Compiled by N. A. HALBERTSMA.

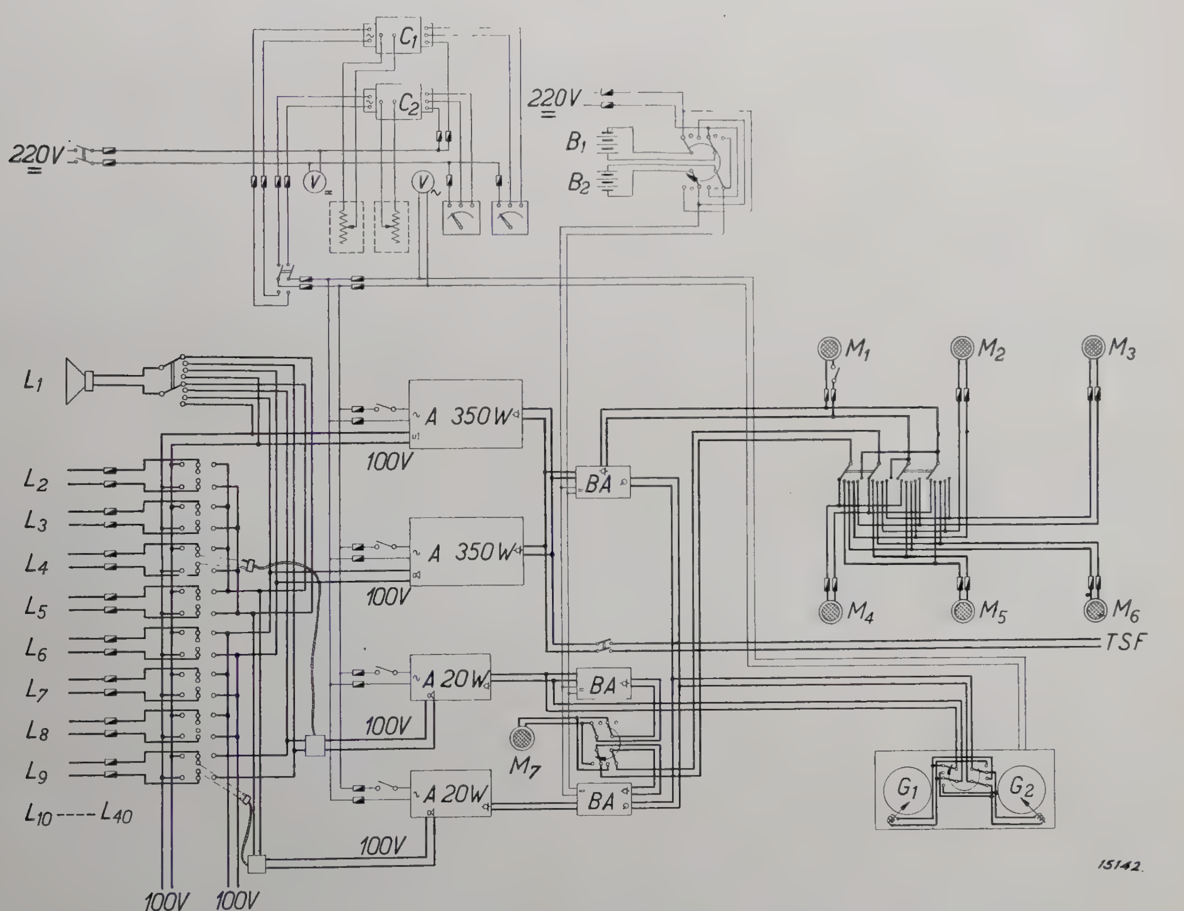


Fig. 6. Simplified circuit diagram of the sound-amplifying installation.

A Amplifiers
BA Impedance matching boxes
B Microphone batteries
C Convertors
G Turntables
L Loudspeaker or loudspeakergroup
M Microphones
V Voltmeters

HOW DOES A WELDING ELECTRODE FUSE?

By J. SACK.

If an arc-welder is asked what he thinks of two particular welding electrodes, he will usually answer that one welds better than the other. The ease or difficulty of welding is closely associated with the conditions of fusion at the end of the electrode. In this article it is not intended to give a complete explanation of the conditions of fusion of an electrode, since many aspects of the problem are still obscure and form the subject of current research. Reference here will be limited to a few of the more common methods of investigation now being employed for studying this problem.

The fusion of a welding electrode cannot be followed in detail with unprotected eyes merely screened against glare by coloured glasses; in fact the formation of drops of metal is only just distinguishable with electrodes which melt slowly and form large drops. The drops are seen to grow, and at the moment of coming into contact with the molten metal in the pool, they become detached from the electrode and merge into the pool. The currents of gas and vapour at the arc and their dazzling light are very troublesome when observations are made with the naked eye.

Observation is facilitated by projecting an enlarged image of the arc on to a projection screen, a method used by Creedy[1]) in his investigations on the influence of the electromagnetic forces on drop formation. It has been found that by a considerable reduction in the welding current, the rate of drop-formation can be decreased so much that the process can be followed on the screen. On the other hand, the fusion process at these low current intensities of, say, 5 amps, differs fundamentally from that obtained at normal currents, e.g. 150 amps. In the former case the drops detach themselves from the electrode in the same way as water drips from a tap, while in the latter case the drops disappear very suddenly with a more or less loud click. This observation was made in investigations with bare electrodes.

The registration of welding conditions on a photographic film, and in particular by means of a slow-motion cine-camera, has constituted a marked advance in these investigations. If an ordinary type of film is used, the interesting part of the process, i.e. the formation and separation of the metal drops is completely masked by the arc. The Chicago Steel and Wire Co [2]) has therefore made use of a special infrared sensitive film and a filter only permitting the passage of infrared (thermal) radiation. These rays are mainly emanating from the glowing metal and the incandescent gases and are able to penetrate through the cloud of vapour surrounding the arc. Pictures were taken at the rate of 60 exposures per second, which on projecting at the rate of 20 pictures per second gave a threefold slowing-down of the actual process. This method for the first time revealed photographically the transfer of material during welding and was applied to all types of bare and coated electrodes. In particular the influence of the chemical composition and the physical properties of the core and coating was studied.

A short time later Hilpert[3]) in Germany also made film records of the welding arc. His apparatus constructed by Thun took 800 pictures per second and thus gave a 40-fold expansion of the actual time of welding. Precautions to cut out the intense glare were, however, omitted, with the result that the light rays from the arc strongly predominated and the drop-transfer could hardly be followed. Nevertheless these records have been useful. They showed that even with a 40-fold retardation, the arc still moved to and fro very quickly. The number of pictures per second was therefore further increased to a maximum of 4000, and the arc and the ambient region no longer registered by means of the intrinsic light but as a silhouette obtained with a more powerful source of light. With these modifications the transfer of material with bare electrodes was studied. In addition to photographic registration, the welding current, the welding voltage and as a time standard an A.C. voltage of 50 cycles were also recorded by means of an oscillograph. In films made at the rate of about 1600 to 2400 pictures per second, corresponding to a slowing down of 80 to 120 times, two types of drop transfer were observed, viz.,

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[1]) F. Creedy, R. O. Lerch, P. W. Seal, E. P. Sordon: Forces of electric origin in the iron arc. (Abstract A.I.E.E. Paper Nr. 32—41). Electrical Engineering **51,** 49, 1932.

[2]) Cf. K. Bung: Der Werkstoffübergang im elektrischen Schweisslichtbogen. Zeitschrift des V.D.I. **72,** 750, 1928.

[3]) A. Hilpert: Werkstoffübergang im Schweisslichtbogen. Zeitschrift des V.D.I. **73,** 798, 1929.

1. a thread-shaped transfer, which may be compared to a narrow stream of metal being poured from the molten end of the electrode on to the piece of work, and
2. a mushroom-shaped transfer where a very thick drop of irregular shape moves to and fro and seems to be reluctant to combine with the piece of work.

The French investigator L. Bull[4]), also took cinematograph pictures of silhouettes of the welding arc. Using heavily-coated electrodes and taking 60 to 80 pictures per second, he observed the rapid transfer of spherical drops without any short-circuit occurring, such as was usually observed with bare and thinly-coated electrodes. These pictures were taken with solar rays, a heliostat being employed to direct a powerful ray of sunlight on to the object being photographed.

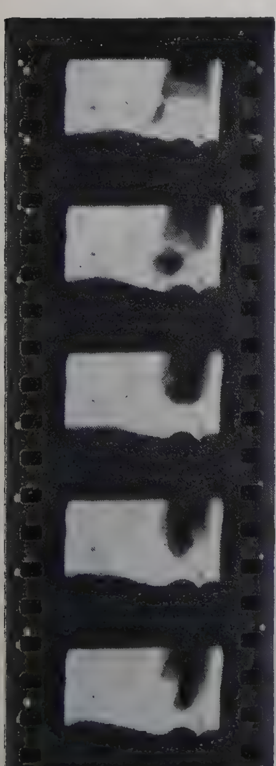
From these methods of direct observation of the welding process, we shall turn to the *indirect methods* which have been devised for the same purpose. First of all the method mentioned above of registrating the welding current and voltage as a function of the time by means of the oscillograph should be considered. A short-circuit on drop-transfer is indicated in the oscillogram as a voltage drop to nearly zero and an increase of the current to the short-circuit value. We are primarily interested in the instant the short-circuit occurs and how long this condition lasts. This information is not only of value as regards the behaviour of the electrodes, but principally as an indication of the efficiency of the welding aggregate as a whole. To this end oscillograms have been employed to determine the intensity of the current-impulses and the speed of adaptation of the welding set to variations of arc length.

As already mentioned the oscillograms show that in general two periods have to be distinguished viz.,

1. the arc-period B, during which the arc burns, and
2. the short-circuit-period K.

If the total time of the drop-period is T, (i.e. T = B + K), it will be interesting to know the ratio B:T or K:T, either as a fuction of the time or as an average over a certain lapse of time. A circuit where a meter indicates and registers the ratio

[4]) Cf. M. Lebrun: La soudure électrique à l'arc et ses applications (1931), p. 39-44.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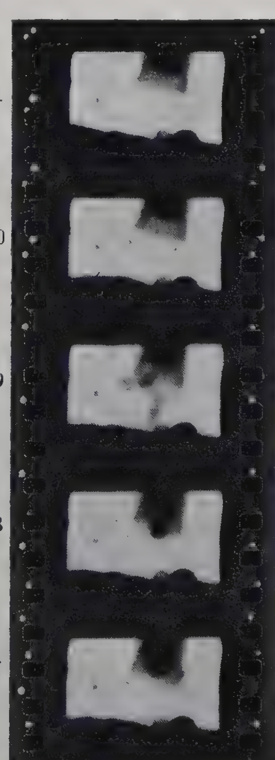
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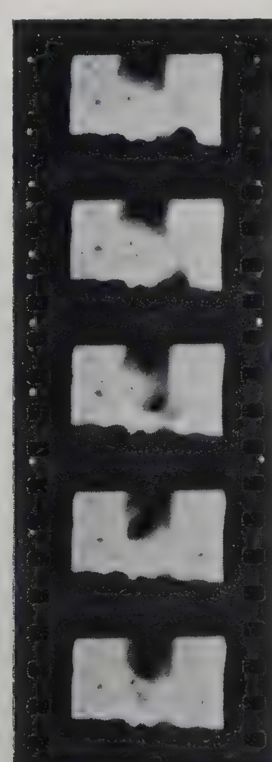
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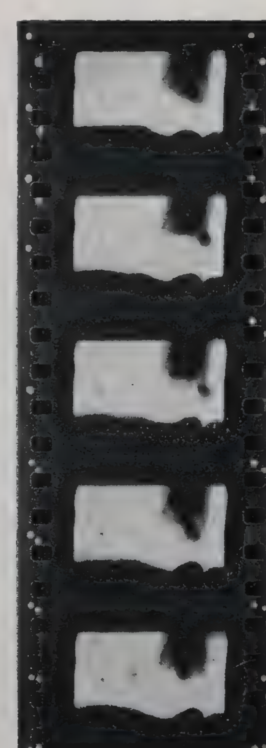
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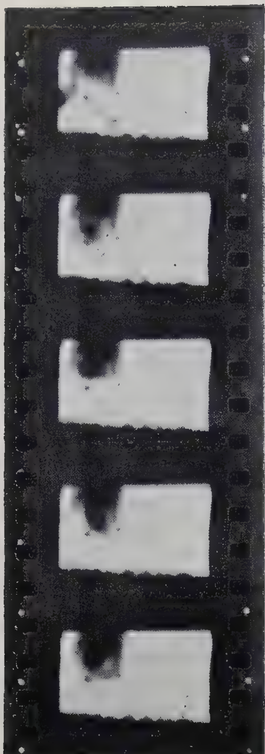
Film exposures recorded by the X-ray cine-camera (cf. p. 29)
The pictures must always be read from bottom to top.

Fig. 1. Drop-transfer. The drop is completely enclosed by coating material.
Fig. 2. The melting point of the metal core and the softening range of the coating must be adapted to each other so that on fusion a sleeve is formed (see fig. 10).

Fig. 3. After contracting (picture 173) an elongated drop (picture 174) is formed which moves to and fro (picture 175) and is eventually transferred to the piece of work (picture 176).
Fig. 4. A metal drop is thrown back to the welding electrode.



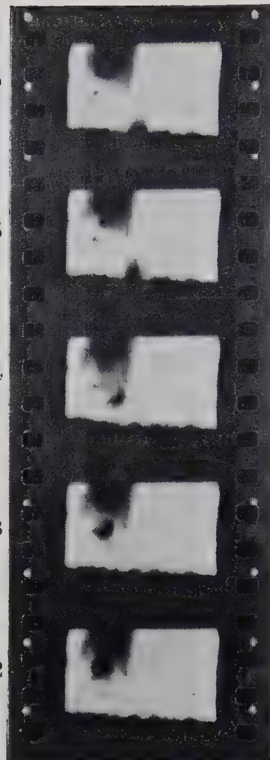


Fig. 5. Gas bubble in the coating (picture 90); 0,02 second later the gas bubble has burst (picture 91). In pictures 92 and 93, the material of the coating appears to "neck" the coating drop.

Fig. 6. A coated drop becomes detached from the welding electrode: during its descent the drop explodes (picture 104).

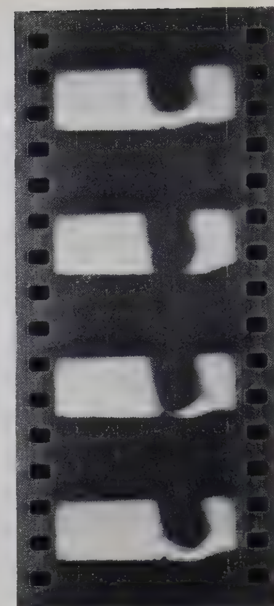


Fig. 7. $12^1/_2$ pictures per second. Over the whole surface of the sleeve the coating fuses into droplets. Core and coating are difficult to distinguish.

Fig. 8. $12^1/_2$ pictures per second. Thinly-coated electrode. The drop falls and causes a short-circuit. The bulk of the molten metal flows into the welding seam.

B:T was used by F l a m m [5]), and afterwards by B e l a R o n a y [6]), who called his apparatus an "arcronograph". It was found that with heavily-coated electrodes the ratio B:T was nearly equal to unity, in other words that the drops during transfer produce no short-circuit (K:T = 0). This result confirms the film records obtained by B u l l.

Finally, reference must also be made to those methods of investigation which cannot be called either direct or indirect methods. We shall group these under the general head of m o d e l e x p e r i m e n t s, as a model is made of that part of the welding process which it is desired to study in greater detail.

A typical example of this class is given by the experiments of F l a m m [7]), who studied the formation and transfer of drops and the capillary forces accompanying these processes by using oil as a medium. From his observations he drew various conclusions regarding the transfer of material during welding.

The investigations of D o a n and his collaborators [8]) also come under this head: they consisted in welding on a continuously-moving band so that successive drops were collected separately. The same applies to the experiments already described at the beginning of this article [1]), where the period

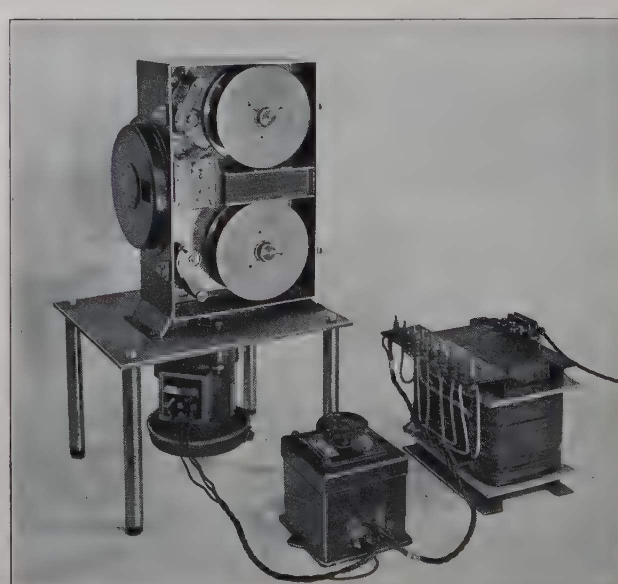


Fig. 9. X-ray cine-camera for taking 50 pictures per second, with cover removed.

[5]) P. F l a m m: Messmethoden und Messungen bei der elektrischen Lichtbogenschweissung. Die Elektroschweissung **3,** 50, 1932.

[6]) B e l a R o n a y: Evolution of the Arcronograph. J. Amer. Soc. Nav. Eng. **46,** 285, 1934.

[7]) P. F l a m m: Die elektrische Lichtbogenschweissung als Kapillarvorgang. Die Schmelzschweissung **9,** 105 and 162, 1930.

[8]) G i l b e r t E. D o a n and J. M u r r a y W e e d: Metal disposition in electric arc welding. Electrical Engineering **51,** 852, 1932.

of drop-formation was extended by employing very small currents, and the experiments of Ronay[6]) in which the electrode was fused against a carbon base.

A method has recently been developed at the Philips Laboratory [9]) to make radiographic film pictures of the transfer of material. The welding process is recorded with X-rays on a special X-ray-sensitive film; if the X-ray tube is run on a suitable voltage it is found that the core and coating of the electrode can be readily distinguished on the radiograph, the method thus being of special value with coated electrodes. But also for bare electrodes the method presents advantages, as the gas and vapour clouds surrounding the arc can be completely penetrated by the X-rays and are hence not reproduced on the film. This enhances the clearness of reproduction.

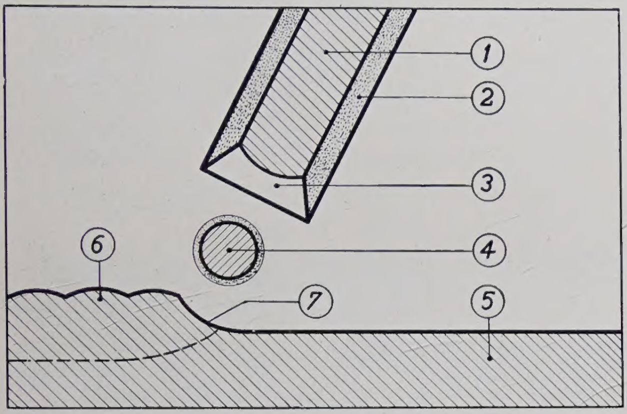


Fig. 10. Diagrammatic sketch of drop transfer from the welding electrode to the workpiece (cross-sectional view): 1 core, 2 coating of the welding electrode, 3 sleeve, 4 drop enclosed by coating material, 5 piece of work, 6 bead, 7 pool.

The first pictures were made with an ordinary amateur cine-camera which was reconstructed for X-ray exposures. With this unit $12^1/_2$ pictures per second could be taken on an X-ray-sensitive film. Subsequent pictures were made with an X-ray cine-camera (*fig. 9*) specially designed for this purpose and with which 50 pictures per second (slow-motion film) could be obtained. *Fig. 10* gives a schematical representation of the drop-transfer; the reproductions *fig. 1-8* shown above are parts of the film and show various stages during the drop-transfer.

[9]) J. Sack: The Iron and Steel Institute. Symposium on the welding of iron and steel, London 1935, Vol. **2**, p. 553.

PRACTICAL APPLICATIONS OF X-RAYS FOR THE EXAMINATION OF MATERIALS [1])

I.

By W. G. BURGERS.

Introduction

The successful application of X-rays to the technical examination of materials does not by any means require a fundamental theoretical knowledge of the laws of crystallography and physics, such as is essential for an exhaustive scientific investigation. X-ray methods have therefore become very useful aids for testing materials and enable valuable results to be obtained also in cases where other means of examination do not succeed. In the modern laboratory, in researches concerned with the structure of matter, an apparatus for taking X-ray diffraction patterns is nowadays as indispensable as the microscope.

It is obvious that satisfactory results cannot be expected without suitable apparatus, which comprise a high-tension generator, an X-ray tube and an X-ray camera. During recent years, X-ray diffraction apparatus have been evolved which are no more difficult to manipulate than the ordinary microscope. The adjoining picture (*fig. 1*) shows the apparatus employed in the Philips laboratory for registering diffraction patterns. The base of this apparatus has a diameter of 10 in., the overall height being 2.5 ft. It is run directly off the alternating-current mains.

[1]) In this section we propose to discuss applications of the socalled interference method only, in which diffraction of the X-rays takes place at the atoms of the radiographed material. No consideration will be given to the absorption method by which structural flaws and other internal abnormalities of a material can be deduced from differences in the absorption of the rays.

The use of this apparatus is quite simple in the majority of its applications. The actual camera is merely a cylindrical box on the inside wall of which the photographic film is secured by springs (in fig. 1 a camera is seen on either side of the X-ray tube); a diagrammatic sketch of the arrangement is shown in *fig. 2*. In the middle of the camera top is the specimen holder which can be rotated about its axis and at the end of which the specimen P is secured. The material to be examined should be pulverised if possible and a little of the powder (a few tenths of a gram suffice, the small quantity required being in fact one of the main advantages of the X-ray method) placed in a thin-walled glass capillary with a diameter of about 1 mm. The X-rays pass through a small metal tube B (diaphragm) inserted in the cylinder wall of the camera and impinge on the prepared specimen, where they are dispersed and produce a series of characteristic interference lines on the film F.

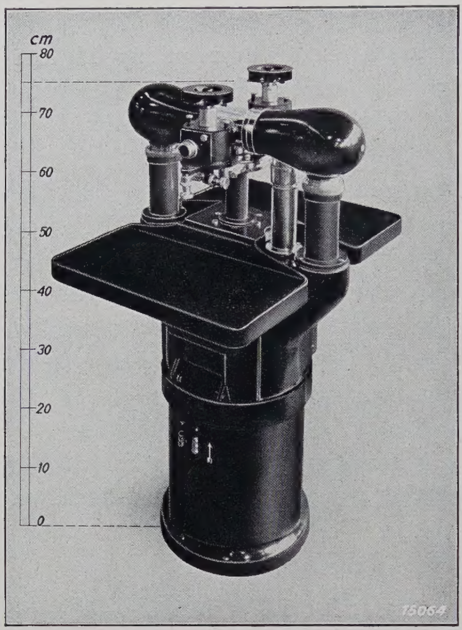


Fig. 1. Apparatus for taking X-ray diffraction patterns.

If the material cannot or must not be pulverised, a different arrangement is used. Thus if the test-pieces are of larger size, they can be secured to the base of the camera with wax so that the X-rays just graze them. Other models of camera with a flat film can also be employed.

With the aid of this handy and portable apparatus it is quite simple to extend the application of X-ray analysis from the laboratory to the work-shop. It is, however, not generally recognised that in practice many cases occur which are particularly suitable for the successful application of this method of analysis, as for instance where definite information is sought on specific points without extensive and complicated investigation. Information of this character can frequently be obtained with surprising simplicity and great accuracy from X-ray diagrams. The diffraction patterns do not require careful measurement nor have complicated theories to be applied; simple inspection is enough, provided a certain amount of experience has been acquired. It is evident that a series of diagrams for a number of commonly occurring materials is very useful for comparison purposes and as a guide in this work.

That up to the present the X-ray diffraction method is applied to practical problems in a limited number of cases only, is probably due to the fact that, on the one hand radiologists have not come in contact with these problems, and, on the other hand investigators employed in the practical testing of materials have not yet fully realised the potentialities of X-rays in their work. Only as a result of a more intense exchange of views and experience will X-ray diffraction methods and apparatus acquire the general application in industrial practice which their practical utility merits.

To contribute to the wider adoption of this method is the purpose of this section, in which we propose to publish periodically examples of applications and results achieved in this laboratory. We shall intentionally limit ourselves to the discussion of problems and cases in which mere inspection of the diffraction patterns is sufficient

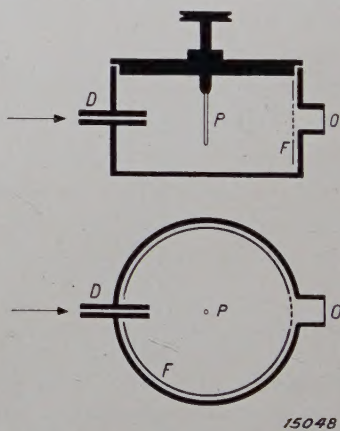


Fig. 2. Camera for obtaining X-ray diffraction patterns. The arrow denotes the entrant direction of the rays emitted by the X-ray tube. D is a diaphragm for producing a narrow pencil of rays, P is the specimen attached to the rotatable holder, F the strip of film clamped to the inner wall. The camera has an aperture at O for the emergence of those X-rays which are not diffracted, in order to prevent disturbing interferences. For the same purpose a hole is cut in the film at this point.

to give the desired result. Problems, whether of a practical nature or not, which necessitate a more fundamental examination will not be embraced in this section.

The examples [2]) to follow will demonstrate the manifold applications of X-ray analysis in practice.

1. Comparison of Porcelains

To determine whether a new porcelain mixture was identical with an existing one, diffraction patterns were obtained for different specimens. *Fig. 3a* reproduces the pattern obtained with the new mixture before firing and fig. 3b the same

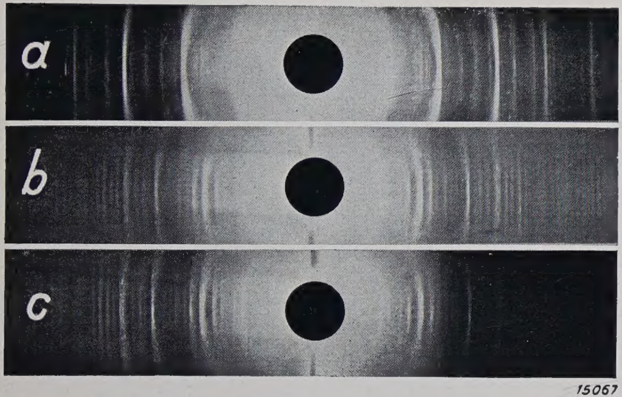


Fig. 3. Comparison of porcelain mixtures.
a) New mixture before firing
b) New mixture after firing
c) Existing porcelain mixture

mixture after firing; fig. 3c shows the pattern obtained with an existing porcelain. The distances between the lines in fig. 3b differ from those in fig. 3a, thus indicating that a structural change has taken place during firing, while on the other hand the exact agreement between the lines in figs. 3b and 3c shows that the fired product is identical with that already known.

2. Identification of Surface Film on Steel Balls

Steel balls which had been in rolling contact with brass bushes gradually acquired a dark surface film, which evidently was extremely thin and adhered tenaciously to the steel surface.

[2]) The majority of these investigations were carried out in collaboration with M. F. M. Jacobs.

It was required to establish the nature of this film without in any way treating the balls either chemically or mechanically. The X-ray patterns for a new steel ball (a) and two balls (b and c) which had been in use for increasing times are reproduced in *fig. 4*; the photographs were obtained by means of radiations just grazing the spherical surface [3]).

While the pattern for an unused ball contains only lines due to α-iron (fig. 4a), another group

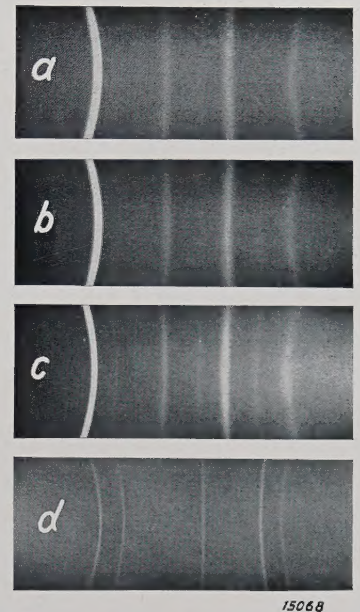


Fig. 4. Identification of a surface film on steel balls.
a) New steel ball before use
b) and c) Steel ball after increasing periods of service
d) Copper

of lines is seen to become gradually more and more apparent as the period of service increases (fig. 4b and c). Simple comparison with a diagram obtained for copper (fig. 4d) shows that the balls are covered with a thin film of copper.

It may also be concluded from the constant distance between the iron lines in all three diagrams, a to c, that the copper film on the balls has not penetrated into the steel with the formation of a solid solution, as otherwise the iron lines would reveal a displacement.

[3]) The different appearance of fig. 4 and fig. 3 is due to the fact that a different method of registration was used. The essential characteristic is the relative position of the lines.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

This section will be devoted to a monthly review of the latest scientific papers published by the N.V. Philips' Gloeilampenfabrieken. Reprints of the majority of these papers can be obtained on application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Holland. Those papers of which only a limited number of reprints are available are marked with an asterisk (*).

No. 1030: E. J. W. Verwey, Ionenadsorpton und Austausch (Kolloid-Zeitschrift **72**, 187-192, August 1935).

Adsorption phenomena in electrolytes may be reduced to three fundamental processes:

a. The adsorption of ions which determine the potential of the double layer;

b. The interchange of oppositely-charged mobile ions in the double layer ("counterions");

c. True adsorption of an electrolyte.

It is shown on the basis of ion interchange in the crystal lattice observed by Kolthoff that these processes are frequently inter-related in a complex manner. The mechanism of "adsorption indicators" is also discussed in some detail. The author shows in conclusion that there is a systematic error in precipitation titrations where the equivalence point is taken as the end point. The practical utility of these titration methods is however not adversely affected by this.

No. 1031: M. J. O. Strutt, Anode bend detection (Proc. Institute of Radio Engineers **23**, 945-957, August 1935.)

The anode direct current is as a function of the grid potential expressed as a series which enables the characteristics of certain modern commercial valves to be accurately represented by no more than three terms. The principal advantage of this form of expression is that the rectification gradient and the distortion effects can be calculated exactly from the static valve characteristics. Certain general conclusions are also drawn regarding the rectification of various incoming waves. Results of measurement and calculation are in very good agreement.

No. 1032*: B. van der Pol, Oplossing van potentiaalvergelijking en golfvergelijking in n, n+1, n+2.... dimensies (Handelingen van het XXV Ned. Nat.- en Geneesk. Congres, 1935).

The fact that a small rotation of a potential or wave function gives rise to another potential or wave function can be employed to derive functions for an n+1 dimensional space from functions in n dimensions. Simple derivation and extension of the general solution according to Whittaker.

No. 1033*: C. G. A. von Lindern, Magnetrons (Handelingen van het XXV Ned. Nat.- en Geneesk. Congres, 1935).

With rotating field oscillations described by Nordlohne and Posthumus, the high-frequency radiation energy generated is considerably greater than with the two earlier known types of oscillations of the magnetrons valve. With a wave length of 100 cm both theory and experiment give an efficiency of 65 percent.

No. 1034*: H. Bruining, Secundaire electronenemissie (Handelingen van het XXV Ned. Nat.- en Geneesk. Congres, 1935).

The depths from which secondary electrons are emitted from metal surfaces are investigated and it is found that these electrons are not derived from the upper atomic layer but from those at a greater depth. Electrons which graze a smooth metal surface cause the emission of more secondary electrons from this surface than obtained on vertical incidence, as the secondary electrons emitted have freer access to the surface.

No. 1035*: W. de Groot, Aard en meting van straling (Handelingen van het XXV Ned. Nat.- en Geneesk. Congres, 1935).

This paper, which was read at a joint meeting of physicists and medical men, deals mainly with the nature and properties of electromagnetic radiations throughout the whole known range of wavelengths. At the end of the paper reference is also made to the latest work on corpuscular radiations.